

BIODIVERSITY AND BIOSYSTEMATIC PRIORITIES: MICROORGANISMS AND INVERTEBRATES

D.L. Hawksworth

and

J.M. Ritchie



**BIODIVERSITY AND
BIOSYSTEMATIC PRIORITIES:
MICROORGANISMS AND
INVERTEBRATES**

This report was prepared and published for the U.S. Environmental Protection Agency (EPA) by the U.S. Government Printing Office (GPO). The views expressed are those of the author and do not necessarily reflect those of EPA or its contractors.

BIODIVERSITY AND
BIOSYSTEMATIC PRIORITIES:
MICROORGANISMS AND
INVERTEBRATES

This report was prepared and published by the CABI Partnership Facility from the UK Overseas Development Administration (ODA), but the views expressed are those of its authors and do not necessarily reflect those of ODA or its officers.

**BIODIVERSITY AND
BIOSYSTEMATIC PRIORITIES:
MICROORGANISMS AND
INVERTEBRATES**

***PRIORITIES FOR BIOSYSTEMATIC RESEARCH
IN SUPPORT OF BIODIVERSITY IN
DEVELOPING COUNTRIES:
MICROORGANISMS AND INVERTEBRATES***

D.L. Hawksworth
International Mycological Institute, Egham

and

J.M. Ritchie
Natural Resources Institute, Chatham

with the assistance of other CAB International Scientific Services Institutes' specialists

*(A.M. Ainsworth, P.F. Cannon, L.M. Gibbons, J.D. Holloway, J. LaSalle, D.W. Minter, C. Prior,
B.J. Ritchie and M.R. Siddiqi)*

CAB INTERNATIONAL
1993

CAB INTERNATIONAL
Wallingford
Oxon OX10 8DE
UK

Tel: Wallingford (0491) 832111
Telex: 847964 (COMAGG G)
Telecom Gold / Dialcom: 84: CAU001
Fax: (0491) 833508

© CAB INTERNATIONAL 1993. All rights reserved. No part of this publication may be reproduced in any form or by any means, electronically, mechanically, by photocopying, recording or otherwise, without the prior permission of the copyright owners.

Published on behalf of

International Mycological Institute
(An Institute of CAB INTERNATIONAL)
Bakeham Lane
Egham
Surrey TW20 9TY
UK

Tel: 0784 470111
Fax: 0784 470909

A catalogue record for this book is available from the British library.

ISBN 0 85198 887 3

Printed and bound in the UK

Preface

Microorganisms and invertebrates have received scant consideration in debates on biodiversity and its sustainable use. The scale of the problem is immense as these encompass 88% of species on Earth, and yet only 5-10% of these groups have yet been recognized and named. In order to further discussion as to what actions should be taken, basic information and guidance as to priorities was required.

This report was prepared by CAB International in response to that need, at the request and with the support of the UK Overseas Development Administration (ODA) - through funds allocated to CAB International's Partnership Facility. Having received the report in February 1993, ODA wished it to be made more widely available, and generously defrayed the costs of its publication to make this possible. I trust that it will be found to be a useful contribution to the biodiversity debate currently in train in the wave of the Convention on Biological Diversity, which received the support of 153 governments and the EEC in Rio de Janeiro in June 1993.

While responsibility for the final text must remain that of the authors, input has been received from many CAB International Institute staff, identified on the title page. For this we are extremely grateful.

In introducing the report, I wish to record my gratitude to Andrew Bennett (Chief Natural Resources Adviser, ODA) for his interest in and enthusiasm for this project.

Professor D.L. Hawksworth

*International Mycological Institute
Egham
6 May 1993*

Preface

Microorganisms and insects have received much consideration in defense and biological control. The scale of the problem is increasing as the number of species on earth, and yet only 1-10% of these groups have been investigated and named. In order to make the most of what is known, basic information and guidance as to priorities is needed.

This report was prepared by the U.S. Overseas Development Administration and with the support of the U.S. Government. The U.S. Government is pleased to have this report prepared by the U.S. Overseas Development Administration. Having received the report in February 1961, ODA wanted it to be made more widely available, and generally to help the work of its personnel in making possible. I trust that it will be found to be a useful contribution to the biological control community in this and other areas of the U.S. Government and the U.S. in the Pacific in June 1961.

While responsible for the final text must remain that of the author, I have been helped from many U.S. Overseas Development Administration staff, identified on the title page. But not all are mentioned. In preparing the report, I wish to thank my friends in the U.S. Government and the U.S. Overseas Development Administration for their interest in and contribution to this project.

International Mycological Institute
London
6 May 1962

Professor D.L. Hawksworth

Executive Summary

- The management and utilization of biodiversity in a sustainable manner is the key challenge now to be faced by humankind.
- Recent calculations suggest that microorganisms and invertebrates together constitute 88% of the species on Earth (31).
- Microorganisms and invertebrates are crucial to the maintenance of biodiversity as: components of community structure; keystone predators/herbivores/pests/mutualists; and environmental bioindicators of habitat disturbance, pollution, and climate change (50-85)
- They can contribute to sustainability in: nitrogen fixation; mycorrhiza formation; maintaining soil fertility; waste utilization; pollination; pest management; human and animal diseases; natural enemies; biocontrol; bioproducts; and quarantine (86-142).
- Only 5-10% of the Earth's species in these groups have yet been recognized, the microorganisms being proportionately half as well-known as the invertebrates (29-32).
- Scant attention has been paid to microorganisms and invertebrates in relation to biodiversity issues in the past, but their vital roles in the maintenance of biodiversity and sheer numbers have led to an increasing recognition that this situation must be redressed.
- This Report has been compiled to assist in the identification of biosystematic priorities in these groups in relation to biodiversity in developing countries (4-8).
- Measurements of the extent of biodiversity in a site by inventorying all species present are impractical for the groups. The DIVERSITAS approach of intensively studying one site and extrapolating from that to other locations, combining standardized sampling methods and easily recorded indicators, is commended (35-49).
- Existing biosystematic resources for microorganisms and invertebrates in developing countries are inadequate to support the demands of biodiversity studies. 91 (64%) of the 142 tropical countries lack any mycological reference collections (148, Annex 1), 67% lack living genetic resource microbiological collections (149, Annex 2), 31% lack any insect collections (150, Annex 3). The situation for nematodes and helminths is worse (151, Annex 4). Information resources, even basic reference lists are often lacking (155-158). In-country human resources are grossly inadequate (159-164) to the tasks, for example 0.5 mycologists per country in Africa (160, Table 1). There is a major need and demand for training and collaborative arrangements (167-176).
- In developed countries biosystematics as a whole is in crisis (177-186) in terms of human resources and its ability to service identification needs (196-197). Yet the reference collections in the UK particularly are almost unparalleled world-wide (187-189), and the UK is pre-eminent in the

compilation and delivery of biosystematic information (190-195). A need for more collaboration and networking between developed and developing country institutions is recognized (198-199).

- Ten priority actions to strengthen biosystematic capabilities in microorganisms and invertebrates in support of biodiversity in developing countries are identified (203).

- 1 Strengthen and increase the effectiveness of biosystematic resources in developing countries through the development of networks with developed country institutions.
- 2 Develop protocols for the standardized sampling of microorganisms and invertebrates for biodiversity assessments.
- 3 Upgrade the basic biosystematic knowledge of microorganisms and invertebrates with key roles in ecosystem functions, bioindication, pest control, waste utilization, food production and human health.
- 4 Develop training and educational aids for the identification of both higher taxa of microorganisms and invertebrates, and to lower levels in groups of particular importance, through well-illustrated manuals and also interactive computerized systems.
- 5 Develop checklists with preferred names to microorganism and invertebrate groups, with type information where possible, and make these available in hard copy and on CD-ROM or other searchable formats.
- 6 Implement compatible data capture, interrogation and transfer systems for collections in both developed and developing countries.
- 7 Assist developing countries in the introduction of microbial isolation, culture preservation, and co-operative screening programmes.
- 8 Develop bioindication systems for the assessment of ecosystem health, particularly for the detection of environmental perturbations.
- 9 Develop biochemical and molecular techniques for the detection and quantification of groups of microorganisms crucial to the maintenance of biodiversity.
- 10 Support and where necessary initiate MSc and PhD programmes conducted jointly by UK universities and biosystematic institutions.

- These Actions would have tangible results in 3-10 years and enable benefiting countries to better meet their commitments under the Convention on Biological Diversity and AGENDA 21 (201).
- Recognizing that various initiatives in this field are currently being planned, implementation should be designed to dovetail and enhance into national, regional, and international programmes wherever desirable (202).

2

Contents

1	Executive Summary	1
2	Contents	3
3	Introduction	5
	Background	5
	Objective	5
	Scope	5
	Definitions	6
	Value of taxonomy	8
	CAB International	8
	Recent initiatives in biodiversity	9
4	Biosystematics and Biodiversity Assessments	13
	What is a species?	13
	How many species are there?	13
	Measuring biodiversity	16
	Species numbers	16
	Genetic diversity	16
	Extensive/intensive sampling	17
	Sampling methodology	18
	Functional groups	18
	Community structure	19
	Keystone resource species	20
	Keystone predators, pests and herbivores	20
	Keystone mutualists	21
	Environmental bioindicators	23
	Bioindication of habitat disturbance	24
	Bioindication of pollution	25
	Bioindication of climate change	25
5	Biosystematics and Sustainability	27
	Nitrogen fixation	27
	Mycorrhiza formation	27
	Maintaining soil fertility	28
	Waste utilization	29
	Pollination	30
	Pest management	30
	Human and animal diseases	31
	Natural enemies	32
	Biocontrol	33
	Bioproducts	34
	Quarantine	35

6	Biosystematic Resources in Developing Countries	39
	Background	39
	Reference collections	39
	Information resources	40
	Human resources	41
	General infrastructure problems	42
	Developing country needs for training and infrastructural support	44
7	Biosystematic Resources in Developed Countries	49
	Background	49
	Reference collections	50
	Information resources	51
	Human resources	52
	General infrastructure problems	53
8	Priority Actions to Strengthen Biosystematics in Support of Biodiversity in Developing Countries	55
9	Literature Cited	61
10	Annexes	71
1	Dried reference collections of fungi (including lichens) within tropical countries.	73
2	Living reference collections of bacteria and fungi (including yeasts) within tropical countries.	79
3	Preserved entomological reference collections within tropical countries.	85
4	Reference collections of plant nematodes and animal helminths within tropical countries.	95
5	Synopsis of numbers of reference collections of microorganisms and invertebrates within tropical countries.	99
6	Numbers of helminth and nematode identifications by the International Institute of Parasitology (CABI) 1983-91.	103
7	Indicators of the resource base for mycological investigations within tropical countries.	107
8	Numbers and geographical origin of trainees at CABI Institutes 1985-92.	113
9	BIONET - The concept for an international network to support regional and national biosystematic services.	117

3

Introduction

BACKGROUND

1 This report has been prepared under the auspices of CAB International at the request of the Natural Resources and Environment Department (NRED) of the UK Overseas Development Administration (ODA).

2 In a letter of 20 March 1992 to Mr D Mentz (Director-General, CABI), NRED indicated that a proportion of the funds committed by ODA to the CABI Partnership Facility for 1992/93 should be used:

"in the identification of priorities for research within
CABI's areas of competence in support of biodiversity
in developing countries"

3 ODA is committed to strengthening its activities in relation to biodiversity issues (ODA, 1991), and is conducting the first triennial review of its Renewable Natural Resources Research Strategy (RNRRS) in 1992/93, during which NRED wished to examine the scope for biosystematics and taxonomy research under the Strategy, taking account of the House of Lords Select Committee on Science and Technology (1992) report on *Systematic Biology Research*, and the *Convention on Biological Diversity* and AGENDA 21 adopted at the United Nations Conference on Environment and Development (UNCED), *The Earth Summit*, in June 1992.

OBJECTIVE

4 To assist in the identification of biosystematic priorities in relation to biodiversity in developing countries in CABI's fields of competence.

SCOPE

5 Priorities for taxonomic research cannot be set without an appreciation of the relative contribution of different groups of organisms to sustainable development and the prudent use of natural resources, nor without reference to the resource base needed to sustain the responsive research programmes needed to service developmental needs in the 1990s and beyond.

6 This report, therefore, seeks to assess the relative importance of the different groups of organisms considered, and from this to identify the priorities for resourcing needed to establish the taxonomic base in developing countries to the level necessary for the effective support of programmes concerned with biodiversity issues.

7 Most concern in relation to biodiversity maintenance and its relevance to sustainable development in developing countries has been focussed on the larger mammals, birds, fish, reptiles, and plants (the "macroorganisms"). However, recognizing that the major part of the world's biodiversity is in invertebrate and microorganism groups, this Report focuses on these, with particular emphasis on groups with which CABI Institutes are concerned. No attempt is made in this report to justify biodiversity research on macroorganisms.

8 In this report, terrestrial biodiversity is the primary concern and attention to marine systems restricted to aspects of coastal environmental damage and fisheries. Exclusively marine or aquatic groups of invertebrates or microorganisms not impinging on these are omitted.

DEFINITIONS

9 *Biodiversity*: A contraction of "biological diversity", first used in 1986. The term embraces the whole variety and range of variation of living things, and its magnitude and cause is one of the key problems of science as a whole (Wilson, 1985). It is often loosely applied as a synonym for "life on earth", but more objectively can be considered at four levels:

- *Genetic diversity* arises ultimately from the self-replicating properties of nucleic acids and the variable sequences of their constituent base-pair molecules which encode the genetic blueprint of all life-forms. Within the genes variation arises spontaneously by mutation and in sexually reproducing organisms by the recombination of parental genes in their offspring. The enormous number of possible combinations inherent in every gene can be selected from by environmental forces at the level of a population of organisms. Such selection determines the evolutionary development and diversification of the population gene pool and is the basis for the observed diversity within species.
- *Species diversity* is the most frequently used indicator of the ecological diversity of ecosystems. The term covers two separate but related concepts, the numbers of species present and their relative abundance. Measures of ecological diversity attempt to describe one or other of these components or to combine both of them in a single measure (Magurran, 1988). However, the relative abundance of species in an ecosystem is never equal; a few species generally are predominant among a larger group of common species while most species are relatively rare. In practice "species richness", a simple count of the number of species present, is frequently employed as the most convenient measure of diversity. Nevertheless this is far from absolute as species concepts are not identical and differ substantially across disparate groups, not least amongst microorganisms which lack sexual processes.
- *Ecosystem diversity* is the sum of all kinds of diversity within an ecosystem. In addition to species richness and abundance, approaches to its assessment are based on community or habitat classification and the measurement of structural diversity of habitats. Another approach is to examine the range of resources used by a species or an individual, the "niche width". To utilize such measures, systems of habitat and resource classification have to be elaborated which relate closely to the needs of the organisms being studied. A further refinement involves measuring the degree of change in species composition (*i.e.* turnover) between sites or samples, referred to as differentiation diversity or beta diversity (Southwood, 1978).
- *Taxonomic diversity*, that is the number of phyla, orders, etc, has been considered more indicative than species numbers in inter-site comparisons. For example, diversity at higher levels of the classification system is higher in marine than in most terrestrial habitats, even though the species numbers are often lower. Similarly a field with one grass and a rabbit is much more diverse taxonomically than a field with a grass and a buttercup. In order to take account of taxonomic diversity, there is a need to recognize and conserve even single species which are distantly related to others even if the habitats

they occupy do not appear otherwise to harbour high diversity as reflected in species numbers. A specific case is the New Zealand Tuatara, a reptile of a class with no other living representative. Arguably the loss of this one species would be more serious in terms of depletion of genetic diversity than the loss of one among a group of closely related lizard species. The biotas of large islands such as Madagascar consist very largely of endemic species well separated genetically from those occupying similar niches elsewhere. The situation is more extreme in microbial groups. On the basis of DNA-relatedness, two bacteria in the same genus can be vastly more remote from one another than plants from different families. Some attempts to allow for phylogenetic differences (evolutionary remoteness) in assessing conservation importance based on the species present are being made (Vane-Wright *et al.*, 1991; Faith, 1992), but a prerequisite for these is an accurate taxonomic base.

10 Biosystematics and Taxonomy. Biosystematics is the study of the relationships and classification of biological diversity, and the processes by which it has evolved and by which it is maintained. Its aim is to produce classifications of living things which accurately reflect their evolutionary history and the degree of genetic difference between them. "Biosystematics" is used in preference to "systematics" as the latter term is also applied to a method of systems analysis, and to emphasize the biological content and experimental validation of modern systematics. Taxonomy and nomenclature are components of biosystematics, while identification is a process systematics makes possible.

- *Taxonomy* is the science of classification. In the case of biology, it is the arrangement of organisms into a hierarchical classification system. Taxonomy predates modern biology and was originally based on superficial resemblances, largely divorced from biological and evolutionary concepts. However, biosystematics now draws on the whole of biology: ecology, physiology, behaviour, biochemistry, genetics, and molecular biology in arriving at a taxonomy reflecting a historical and biological reality. In practice the subtle difference between (bio)systematics and taxonomy is often blurred, and either term is often used interchangeably.
- *Nomenclature* is the process by which the units the taxonomist decides to distinguish are provided with names. Names are the unique labelling code by which the huge diversity of living things are assigned independent but related identities within the overall classification. Without such a system communication, interpretation and manipulation of biological information would be impossible in all aspects of pure and applied biology. The rules which regulate the scientific names to be applied in a particular case are *Codes* of nomenclature developed and operated through international scientific organizations. There are three main *Codes*: *Bacteriological*, *Botanical*, and *Zoological*.
- *Identification* is the process by which particular specimens are referred to particular units (e.g. species) recognized by biosystematists. It is consequently a process made possible by biosystematics, but is not necessarily undertaken by biosystematists or taxonomists -- and rather by biologists needing to determine the scientific names for organisms they are working with. Identification is sometimes erroneously confused with taxonomy *per se*.

11 Microorganisms. There is no unambiguous definition, but for this Report, the following definition is adopted: Organisms which *either* belonging to phyla many members of which either cannot be seen by the unaided eye, *or* where microscopic examination, and in many cases growth in pure culture, is essential for their

identification (Hawksworth, 1992a). In this sense the term encompasses: algae, bacteria, fungi (including yeasts and lichen-forming species), protozoa, and viruses. Fifty-two of the world's 95 phyla of living organisms fall within this concept of microorganisms.

VALUE OF TAXONOMY

12 Taxonomy is concerned with the naming of life. It generates the language for biodiversity investigations through the system of classification it develops. The species names can be viewed as the individual words which make all living communities describable. The names provided by taxonomy are also the essential reference labels which provide access to the accumulated knowledge in the world's scientific literature relating to all living organisms. Without scientific names, new knowledge cannot be assimilated and related to what is already known. It also follows that without correct identifications pertinent literature cannot be accessed and that erroneous information can enter the knowledge systems.

13 Taxonomy has a further importance in the management of natural and managed ecosystems in that the whole biology of an organism is implied in its scientific identity and its place in the systematic hierarchy. A species name provides a set of hypotheses about the likely performance of an organism in any context, since even if a species is poorly known, its nearest known relatives will offer an approximate picture of the place that organism is likely to play in the ecosystem, and will throw up a series of specific questions which must be answered to establish more closely the role of the newly recognized species. Incorrect identifications can not only frustrate and mislead other investigators by leading to incorrect predictions or hypotheses, but also be extremely costly (Danks, 1988; Hawksworth, 1985). Unsatisfactory classifications similarly limit the value of predictions or hypotheses.

CAB INTERNATIONAL

14 CAB International is the third largest employer of taxonomists in the UK. They are located in three specialist institutes, each with a vital interest in taxonomy and biosystematics and their relationship to development, and are key providers of biosystematic expertise in relation to invertebrates and microorganisms. The three biosystematic institutes, the *International Institute of Entomology* (IIE), *International Mycological Institute* (IMI), and *International Institute of Parasitology* (IIP) cover the fields of entomology, mycology (including plant bacteria) and parasitology. Within their fields, the institutes conduct research, provide identification services, develop (and in two cases maintain) world-class reference collections, prepare reference publications, training (both in-house and overseas in conjunction with developing country institutions), and operate consultancy and contract services through which this expertise is applied to the needs of both developed and developing countries. However, within the broad remit of the CABI Institutes, important groups of organisms needing taxonomic research are identified, whether or not CABI currently employs permanent staff expertise on those groups.

15 The *International Institute of Entomology* (IIE), founded in 1913, is situated close to The Natural History Museum (NHM) in South Kensington. It employs nine taxonomic specialists, covering the major insect groups of importance to tropical agriculture, who work alongside the entomological staff of the NHM. In conjunction with NHM staff, IIE provides an international identification service on insect pests (beetles (*Coleoptera*), moths (*Lepidoptera*), flies (*Diptera*), bugs (*Hemiptera*)) and their natural enemies (especially parasitic wasps (*Hymenoptera*)). IIE does not maintain its own reference collections but utilizes the 30 million in the

Museum, to which it contributes specimens and helps curate. Staff conduct research on the taxonomy of these insect groups leading to the publication of identification manuals and monographs (e.g. fruit-flies of economic importance) and provide the specialist support required for biological control (*para 124-130*) and other projects (for example pin-pointing the probable origins of the introduced pine aphids in Africa). Maps of pest distribution and the *Bulletin of Entomological Research* are both prepared at the Institute.

16 The *International Mycological Institute* (IMI) was established in 1920 at Kew, and relocated to a new site at Egham in 1992. It is the largest of the CABI biosystematics institutes, and the world's major mycological centre. Its staff of 65 includes 12 taxonomic specialists who support its identification service, training, research, and outreach contract and consultancy programmes (in plant protection, biodeterioration, environmental contamination, food spoilage, and industrial and medical mycology). The identification service covers plant pathogenic bacteria and all fungi (other than larger basidiomycetes). IMI staff prepare numerous research papers, description sheets, distribution maps, reference works, and the authoritative *Index of Fungi* and *Bibliography of Systematic Mycology* which uniquely document all new names and publications relating to the taxonomy and systematics of fungi (these are the mycological equivalents of the *Index Kewensis* and *Kew Record*). The taxonomic work of IMI is backed by a comprehensive library and reprint collection, dried reference collection of over 355,000 specimens and a genetic resource collection of 16,500 isolates of living fungi (incorporating the UK National Collection of Fungus Cultures). This collection, one of the three largest service fungal culture collections in the world, co-ordinates UK input of the 10 UK national microbial collections into the EEC-sponsored Microbial Information Network Europe (MINE), and is one of 24 Microbial Resource Centres (MIRCENs; Da Silva, 1991) world-wide recognized by UNESCO.

17 The *International Institute of Parasitology* (IIP), based at St Albans, conducts research on systematic and applied aspects of helminth parasites of animals (including man, domestic animals and fish) and on nematodes affecting plants and insects. The institute employs five professional taxonomic specialists who provide information and training on the taxonomy, biology, distribution, host range and pathology of helminths and nematodes and publish identification guides based on their research. IIP also maintains comprehensive reference collections of helminths and nematodes of major international importance (complementing those in The Natural History Museum).

18 In addition, CABI's *International Institute of Biological Control* (IIBC), undertakes research and implementation programmes, as well as providing information, advice and training, on biological control of major pests and weeds. IIBC is, therefore, a major customer for taxonomic services in relation both to target pests and weeds, and the insects and microorganisms of potential value as biocontrol agents. Several of its staff are recognized authorities on the taxonomy of particularly groups, notably entomopathogenic fungi, parasitoids, and weed pathogens. The headquarters of the Institute are at Silwood Park, and stations are also maintained in Kenya, Malaysia, Pakistan, Switzerland, and Trinidad.

RECENT INITIATIVES IN BIODIVERSITY

19 The creation in 1989 of the Global Environment Facility (GEF) under the administrative control of the World Bank, UNDP and UNEP, aimed to assist developing countries in protecting the "global commons". One of the four areas identified for funding was biodiversity, with one specific aim being to preserve areas containing genetic resources of especial value to mankind in terms of harvestable products.

20 The *Global Biodiversity Strategy*, developed by the World Resources Institute, IUCN and UNEP (Courrier, 1992) aims to provide concrete guidelines for action in the conservation and sustainable use of biological diversity. It is the culmination of a three-year programme of workshops and consultations under the sponsorship of several major aid agencies (including ODA). The *Strategy* is built around 85 specific proposals for action by governments and NGOs. With its emphasis on practical action, the strategy is seen as complementary to the legal framework provided by the *Convention on Biological Diversity*, negotiated under the auspices of UNEP, which is in the process of adoption by most countries in 1992.

21 Another important programme *Ecosystem Function of Biodiversity* now known as DIVERSITAS was launched in 1990 under the joint sponsorship of the International Union of Biological Sciences (IUBS), the Scientific Committee for Problems of the Environment (SCOPE) of the International Council of Scientific Unions (ICSU), and UNESCO. This research programme has considered how species diversity contributes to ecosystem functioning and has held a series of important workshop meetings on biodiversity-related topics (Solbrig, 1991; Solbrig *et al.*, 1992), including one focussing on microorganisms (Hawksworth & Colwell, 1992) leading to an action plan MICROBIAL DIVERSITY 21.

22 The *Convention on Biological Biodiversity*, a key component of the AGENDA 21 of the UN Conference on Environment and Development (UNCED) held in Rio de Janeiro in June 1992, has as its objective "to conserve the maximum possible biological diversity for the benefit of present and future generations and for its intrinsic value". The Convention stresses the need for the sustainable use of biological resources and the need for funding by developed countries in support of developing countries to facilitate conservation of biodiversity. It also highlights the need for technology transfer to enable developing countries to exploit their own genetic resources and the need for fair sharing of the benefits of exploitation of those resources. A major initial focus of the Convention is on information gathering at national level through Country Studies, a process involving surveys and inventories. A format and methodology for these reports has been prepared by UNEP. Of particular interest from the standpoint of taxonomic research inputs are the need for species and ecosystem diversity data, including changes in status over time, and assessment of areas of high species endemism.

23 The International Geosphere-Biosphere Programme (IGBP) has drawn up an ambitious plan to study Global Changes and Terrestrial Ecosystems (Steffen *et al.*, 1992) for which international support is being sought.

24 As a contribution to the *Global Biodiversity Strategy* (para 20), the World Conservation Monitoring Centre (WCMC) has compiled a major report *Global Biodiversity: Status of the Earth's Living Resources* (Groombridge, 1992); this is a source book of current knowledge on all aspects of biodiversity including its extent, value, protection and relevant international conventions. WCMC see this work as a catalyst for the necessary data gathering and monitoring needed to support the operation of the Convention and other major international initiatives.

25 The Commonwealth Science Council (CSC) has since 1986 coordinated a programme *Biological Diversity and Genetic Resources* (BDGR) largely devoted to plant resources. At the planning meeting of the BDGR Network in June 1992 it was decided to continue and extend the programme to cover animal and microorganism diversity and genetic resources. A major feature of the programme will continue to be the preparation of National Biodiversity Status Reports along lines similar to those proposed by UNEP. These include surveys of existing data on biodiversity and preserved and living collections of biological material. Under its BDGR programme CSC, along with CASAFA and CABI, jointly organized an

international workshop in 1990 on *The Biodiversity of Microorganisms and Invertebrates: Its role in Sustainable Agriculture* (Hawksworth, 1991b).

Biosystematics and Biodiversity Assessments

WHAT IS A SPECIES ?

26 The species has been defined by Mayr (1969) as "groups of interbreeding or potentially interbreeding natural populations that are reproductively isolated from other such groups". One problem of this definition is that many microorganisms, particularly bacteria, unicellular algae and viruses, are not sexual and so the concept of reproductive isolation cannot be applied; although many fungi have sexual stages) and when they do inability to culture them precludes experiments. At the same time, complex breeding systems have been found to operate within morphologically defined fungus species, and vegetatively incompatible groups are found within asexual fungi. In bacteria, species separations based on percentage DNA homologies have been recommended but these tend to be much lower (70 %) compared with differences amongst higher mammals (98 % between man and chimpanzees). The need to have a special workshop on species concepts in microbial groups has been identified by IUBS/ IUMS (Hawksworth & Colwell, 1992).

27 The array of species definitions has been summarized by Vane-Wright (1992). The phylogenetic species concept places the emphasis not on reproductive isolation but on patterns of differentiation based on morphological features or more recently on sequences of nucleic acids in the genetic material. Such differences in outlook may alter the species or subspecies rank assigned to particular populations. No absolute resolution of this problem is possible and species will continue to be defined by relational criteria. It has been eloquently argued that there is a case for pluralism in species concepts (Mishler & Donoghue, 1992). In practice microbiologists tend to recognise as species populations with a high degree of morphological, biochemical or molecular similarity and which produce replicating lineages (Hawksworth, 1992b).

28 The inescapable conclusion from these considerations is that "species" in different groups are not necessarily equivalent in terms of genetic diversity.

HOW MANY SPECIES ARE THERE ?

29 The number of species of organisms known to science is authoritatively estimated at approximately 1.7 million (Hammond, 1992). Precise numbers are difficult to provide because of the absence of a single comprehensive catalogue, widely dispersed literature, the variation in the status accorded to particular species names by different authors, and the substantial numbers of invalid and synonymous names in use. The larger the groups concerned the more imprecise the estimates. In any case, it is now recognized that the vast majority of all living species are still unknown to science. In the case of microorganisms and invertebrates only 5-10% of the world's species have been formally named. This situation is in stark contrast to the 65-100 % estimates for macroorganism groups, including flowering plants, birds, reptiles, fish and mammals (House of Lords Select Committee, 1992).

30 Various methods have been used in attempts to estimate the numbers of unknown species by extrapolating from existing information. The sampling of neotropical tree canopies for beetles led Erwin (1982) to postulate 30 million arthropod species world-wide. Similar studies on arboreal bugs in Indonesia led

Hodkinson & Casson (1991) to suggest a lower global figure, for insect species alone, of 2 million. Recent estimates of numbers of fungal species (Hawksworth, 1991a) based on extrapolations from different data sets conservatively suggest at least 1.5 million fungi; from a survey of fungi on selected hosts in Australia, Pascoe (1990) has indicated that a figure as high as 2.7 million may be appropriate. Additional substantiating data are reported in Hawksworth (1993a). The unculturable bacteria are perhaps the most neglected group, however, if guesstimates of 2-3 million, compared with 3,100 described, are accepted (Trüper, 1992).

31 Estimates of species numbers for all major groups from various sources have been critically analyzed by Hammond (1992) to show the current proportions of the known (**Fig. 1**) and unknown (**Fig. 2**) species in major groups of organisms. This critical synthesis combines informed guesswork with knowledge and awareness of distribution patterns and likely biases of sampling methods employed. It leads to a current working figure of 12.5 million species for the global biota as a whole, and suggests that microorganism and invertebrate groups, the subject of this Report, constitute 88% of the world's biota.

32 The most striking feature of these figures is the enormous preponderance of insects among presently known species, and the fact that this preponderance is likely to exceed 64% of the true total. Within this total the share allotted to *Hymenoptera* (bees, wasps and ants) is expected to rise from 7.7% of known species to a massive 19.3% of the eventual total species number. Gaston (1991) concluded that *Hymenoptera* are the most diverse order of insects in several temperate regions and in tree canopies in rain forest in Borneo *Hymenoptera* were the most species-rich group, accounting for just over 25% of all arthropod species present (Stork & Brendell, 1993). The proportional representation of *Diptera* (true flies) is also likely to almost double. At the same time it is pertinent to note that while the microbial groups constitute only 9.5% of the known world's biota, they are given as comprising 18.4% of that actually occurring, roughly doubling. That the number of arthropods would rise more modestly from 55.9% to only 70.3%, suggests that the microorganisms are proportionately much less well known.

33 The *Nematoda* are a poorly inventoried phylum whose species numbers are expected to grow as knowledge increases. Although 15,000 species are known, the true number has been estimated at between 500,000 and 1 million species. However, recent samples from deep-sea sediments have shown such high apparent diversity that if the variety of forms observed are shown to represent species, then the nematodes might rival the insects in overall species numbers (Groombridge, 1992).

34 Given the phenomenal densities of nematodes in some environments, with up to 30 billion individuals per square metre in temperate grassland (Sohlenius, 1980), there is clearly a need for better data on the species richness of nematodes in marine and terrestrial environments. Hammond (1992) singles out the microorganisms, including fungi, together with nematodes, for particular mention as needing better sampling data, especially on the rate of species turnover within and between tropical habitats. He notes:

"If tropical to temperate species richness ratios are to be established for these groups, there will be a need to develop sampling methods and protocols that allow reliable comparison between sites without a complete inventory being taken".

Figure 1. Major groups of organisms: described species as proportions of the global total (Hammond, 1992).

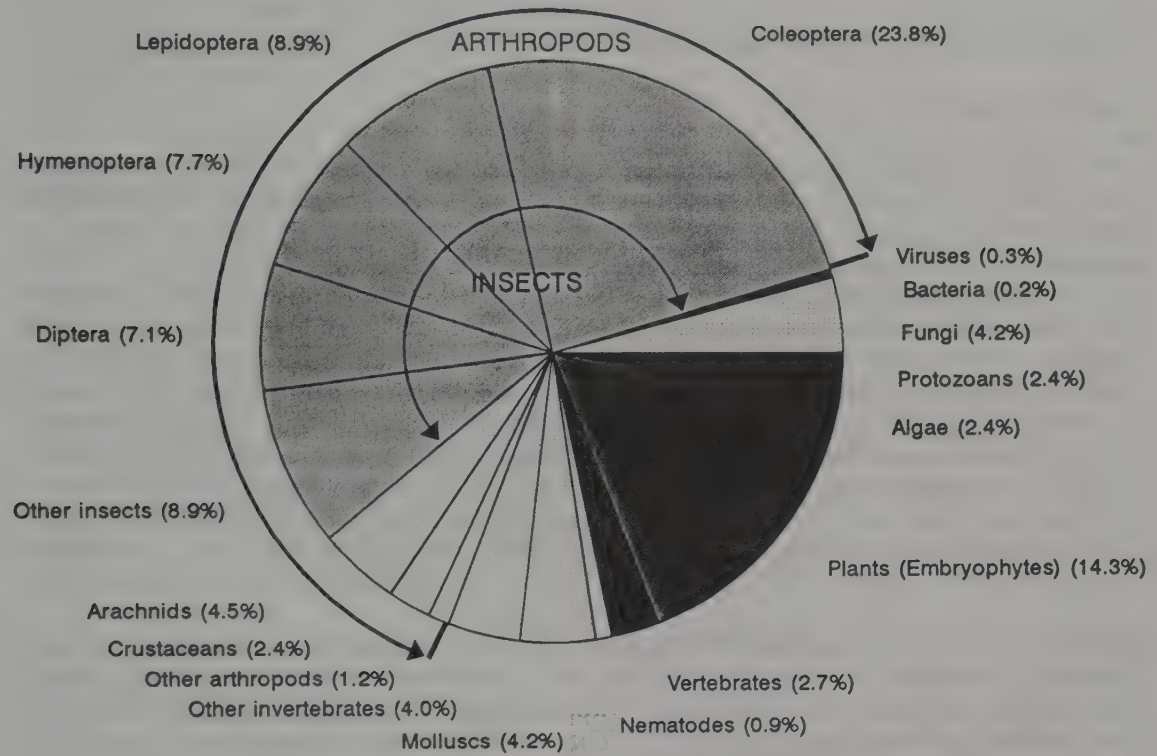
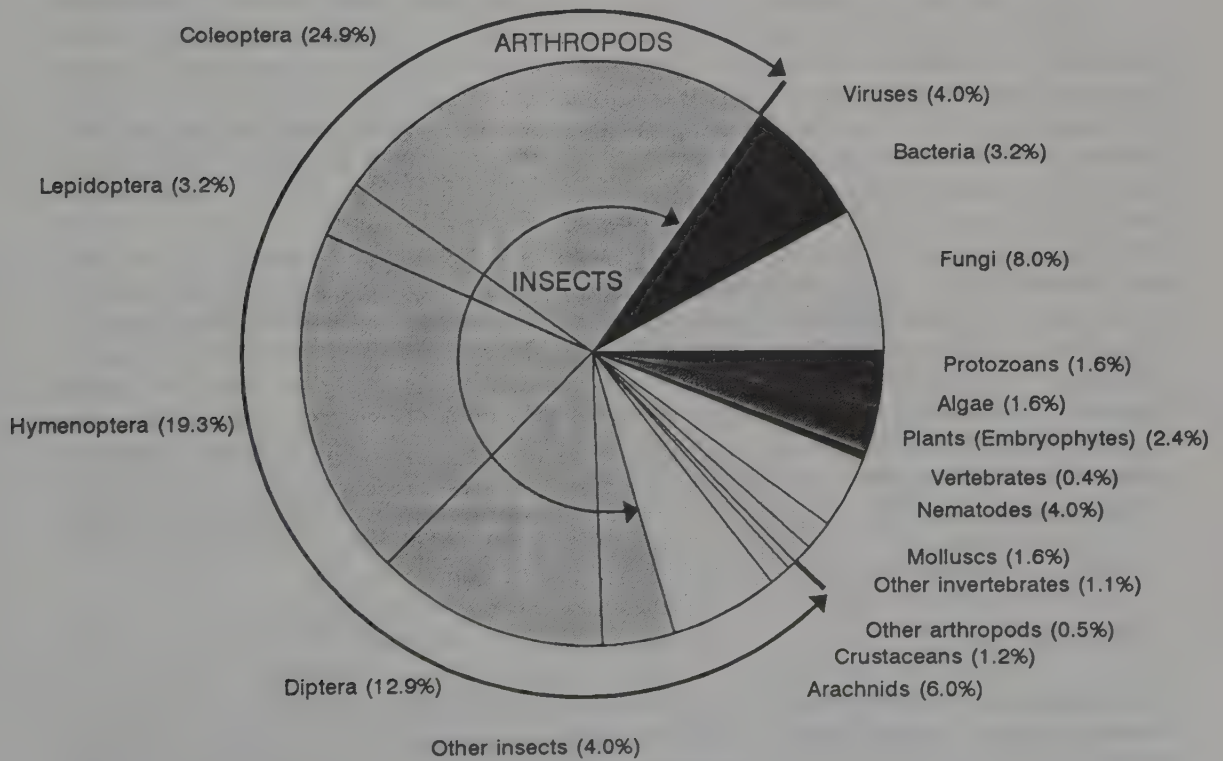


Figure 2. Major groups of organisms: possibly- existing species as proportions of the global total (Hammond, 1992).



In these groups, new techniques of species recognition and discrimination are urgently needed to address the scale of the problem.

MEASURING BIODIVERSITY

Species numbers

35 Where many groups of common organisms are sampled from a given habitat, if species abundances are shown graphically against the numbers of individuals of each species present, they commonly exhibit a characteristic humped, *i.e.* log normal, distribution with samples approximating to a log-series (Magurran, 1988). The significance of this is a matter of active dispute amongst theoretical ecologists but its practical value lies in indicating the relative health of an environment. For example, changes in the species abundance curves of diatom communities are used as a measure of water quality. Under polluted conditions the log normal distribution of the healthy undisturbed community flattens out towards a geometric series distribution characteristic of a stressed or disturbed community (Patrick, 1973). In effect most species become rare while a few tolerant species become numerically dominant, *i.e.* there is a greater dominance factor. In extreme cases where extinction is being approached evenness also approximates to a geometric series.

36 At present no single site on Earth has been inventoried for all species present. Indeed this may be unachievable for all microbial and invertebrate groups, particularly because of the shortage of appropriately trained scientists in developed as well as developing countries. The DIVERSITAS programme (*para 21*) envisaged selected sites being inventoried in depth (intensive sites) and the numbers of more easily surveyed indicator groups being examined in others (extensive sites) which by extrapolation could provide an approximate measure of relative richness (DiCasteri *et al.*, 1992).

37 The problems of inventorying microbial (including many fungal) groups are especially acute as (a) isolation into pure culture and the application of biochemical tests can be crucial to arriving at identifications, and (b) it is evident that numerous currently unculturable bacteria present in nature can only be detected by molecular methods. In relation to the discussions on the DIVERSITAS programme, in 1992 the cost of inventorying a single site was estimated as US\$ 8 million, of which 5 million was considered necessary for the microbial groups.

38 Even such an all-taxon inventory project (*para 45*) is unlikely to be fully comprehensive for microbial groups. Even in the case of those fungi that can be collected by eye and hand-lens, species lists grow gradually over extended periods. There is a strong correlation between the length of study, the number of species found, and the percentage of novel species detected in temperate as well as tropical regions. Short visits to the tropics tend to yield 15-30% fungus species new to science, while even for the *larger* fungi 50-70% can be expected over a 10-15 year span of *in situ* studies as evidenced by work in Malaysia and Puerto Rico (Hawksworth, 1993a). To stress the scale of the problem, of 148 species of *larger* fungi found in a 2.5 m strip either side of a 7.5 km single track in Cameroon in 1989-91, 82 (55%) were undescribed (R. Watling, pers. comm.).

Genetic diversity

39 Species numbers alone do not reflect the total biodiversity in a site. There is concern among microbiologists that the declining range of many wild populations of plants and animals is leading to a decline in the amount of genetic diversity in the remaining populations of those organisms. Historical cases of domesticated plants

with a narrow genetic base being affected by epidemic disease are numerous (for example the Irish potato famine resulting from fungus disease (*Phytophthora infestans*) decimating a staple crop) and projects are under way in many institutions to protect the genetic diversity of human food crops, most notably by networks of seed banks integrated by the CGIAR-supported International Board on Plant Genetic Resources (IBPGR).

40 The amount of variation within fungi below the morphological species in pathogenicity, DNA RFLP's, isozymes, and incompatibility groups is enormous. While this is recognized in many plant pathogens (e.g. Parlevliet, 1986), its extent is largely unknown in natural populations. While substantial variation in features such as metabolite and enzyme production are known within particular microorganisms, little is known of the effects of anthropogenic population reductions on the genetic diversity of populations of invertebrates and microorganisms. The Harvard Forest Workshop (Solbrig, 1991) proposed investigating differential population survival of artificial populations of bacteria, yeast or algae in model systems. The Workshop also proposed investigations of the effects of habitat fragmentation on genetic diversity. Mycorrhizas of forest trees isolated by clearance for agriculture are an important candidate group in which to examine this effect.

Extensive/intensive sampling

41 The crucial question of establishing scientific research protocols for large-scale biodiversity inventory and monitoring has been addressed by the IUBS/SCOPE/UNESCO DIVERSITAS programme (DiCatri *et al.*, 1992; *para* 37). Given the size of the problem, it proposes that resources are focused on both intensive and extensive sampling. *Extensive sampling* would use standardized, quantitative, repeatable protocols of sampling and estimation applied to matched sampling sites in different biomes (habitat types). *Intensive sampling* at a smaller number of equivalent adjoining sites would provide a complete species inventory for selected groups which could be used to calibrate the standardized sampling by developing correction factors.

42 The terrestrial biomes selected as priorities to be inventoried and monitored under this programme were initially set at five: tropical rainforests and savannas, temperate forests and grasslands and the polar tundra. Criteria for selecting taxonomic groups of organisms for priority in sampling involved five important considerations: they should represent the major functional groups (see *para* 43), the range of size and growth forms, the range of distribution characteristics (narrowly endemic to cosmopolitan species), representatives of groups with many and few species, and any discernible keystone species or groups (see below). The existing network of UNESCO MAB Biosphere Reserves (currently 270 reserves in 70 countries) were envisaged as providing most of the initial survey sites.

43 DiCatri *et al.* (1992) proposed that the specific groups to be used for this sampling programme should include, in addition to trees and other plants and vertebrates, spiders, lichens, mycorrhizas and other fungi to be specified, and a few specific groups of insects to include a few which are well-known (dung beetles, tiger beetles, and butterflies).

44 Sampling programmes and the selection of conservation sites need to take into account the complexities of invertebrate habitat requirements. In Costa Rica hawkmoths migrate seasonally between forest areas on the Atlantic coast and the western dry forests (Janzen, 1987). Helminth parasites of vertebrates often require aquatic habitats with available intermediate hosts in addition to viable terrestrial habitat for their final host (L R Gibbons, pers. comm.). Many larger fungi are also seasonal where the climate is not constant throughout the year.

45 Apart from the problems of cost (see *para 37*), the manpower to undertake such an intensive survey would be enormous, and the problems are massive given the current crisis in the numbers of systematists. Indeed, there are no specialists available able to rapidly identify many groups and to assess which of the numerous taxa are new. A workshop to address the practicality of producing an "All Taxa Inventory" for a site is to be convened by Dr D Janzen in Philadelphia in April 1993.

Sampling methodology

46 Diversity measures are most informative and easiest to interpret when they are applied to fairly limited, and well defined, taxonomic groups (Magurran, 1988). It is in the selection and definition of appropriate groups and the understanding of the data gathered that taxonomy can make an important contribution.

47 For insects and other macroinvertebrates some proven standardized sampling techniques already exist (Hammond, 1990; Coddington *et al.*, 1991). By comparison the development of simple quantitative sampling procedures for microorganisms would seem to be a priority. The IUBS/SCOPE/UNESCO Harvard Forest workshop on priorities for biodiversity research proposed numerous testable hypotheses with respect to species richness (Solbrig, 1991). There are two basic methods of using sampling to make estimates of species richness without making an exhaustive inventory. Parametric and non-parametric statistical techniques make assumptions about the dispersion and distribution of species and their relative abundances and estimate species richness accordingly. Calibration methods make the general assumption that ratios deduced from a known situation will hold in an unknown situation.

48 The Harvard Forest Workshop advocated using data from representative sites to evaluate analytical methods, use of modelling and simulation techniques and theoretical work on statistical issues. It recommended that a workshop should be held to develop and evaluate techniques of estimation of species richness from standardized sample data. Such a meeting would bring together systematists, ecologists, and statisticians.

49 By developing analyses of areas with rich concentrations of endemic plant species Myers (1990) has shown that 20% of the world's plant species are confined to 0.5% of the world's surface in areas he has termed "hotspots". An extension of this approach to identifying priority areas for biodiversity conservation has been pioneered by The Natural History Museum using a WORLDMAP system to indicate optimal sequences of areas that contain the maximum amount of taxic biodiversity (Vane-Wright *et al.*, 1991). So far the system has been used on selected groups of organisms for which good world-wide data exist (e.g. bumble-bees, butterflies), but the results are not necessarily congruent with taxic diversity (Faith, 1992). There is a need, however, to obtain data sets for selected groups at other trophic levels (saprobies, predators) for comparison. This effort would involve major inputs of taxonomic research if valuable data are to be obtained in the medium term.

FUNCTIONAL GROUPS

50 Microorganisms and invertebrates, almost without exception, receive scant attention in considerations of action needed to conserve natural ecosystems and to utilize natural resources in a sustainable manner. However, these organisms perform functions vital to ecosystem maintenance and health and it a key component of any scientific long-term management or development plan must be the monitoring of those functional groups. Information is especially poor for tropical

forests, where selective taxonomic research inputs is a prerequisite for the investigation and communication of data on ecosystem function.

Community structure

51 All living communities ultimately depend on microorganisms (Price, 1988). Most also depend on the capture of solar energy by primary producers are able to build organic biomass by the fixation of atmospheric carbon dioxide through photosynthesis. Plants, algae and some bacteria share this capacity and provide the basis of energy inputs into the community. Much of the biomass of organisms occurs at this level and successive trophic levels of consumers form a pyramid of reducing biomass. The primary consumers of this production of biomass include many phytophagous invertebrates and microorganisms which in turn are consumed by predatory groups of invertebrates (including large numbers of parasitic wasps) and ultimately a more restricted group of top predators including mammals and birds. All dead plant and animal material and waste products are then consumed by scavengers or broken down by decomposers, especially fungi and to a lesser extent other microorganisms. The nutrients released become available both to plants and to small invertebrates (including some nematodes and many insects) which feed on the microorganisms.

52 Food chains and food webs of great complexity exist within stable environments such as tropical forests. Out of the many thousands of organisms present, mostly not known to science, it is important to have some basis for selection of particular groups for study. One such rationale is to choose prominent examples of functional types representative of the different trophic levels within the community. These may be further subdivided in terms of functional analogues, organisms which are either closely related species partitioning the same resource, such as food, or organisms of different origins which have converged to exploit the same resources (Solbrig, 1991).

53 If several functionally similar species (functional analogues) are present in a functional group then the extinction of one or more species may not affect the function. The extinct species can then be said to be functionally redundant. In reality, however, it cannot be confidently asserted that two species carry out precisely similar functions. For example, whilst a range of basidiomycete fungi are involved in wood-decay, the extent to which they utilize different ligno-celluloses and other compounds is uncertain. Further, the range of environmental conditions under which they can operate may differ. The complexity of the range of interactions between species is immense, and food-chains and -webs are also rarely worked out to the microbial base. In the case of many small mammals and birds, it is rarely appreciated that these can have key roles in the dispersal of mycorrhizal fungi and so contribute to forest vigour (Pirozynski & Malloch, 1988).

54 Suspected cases of redundancy may often be more apparent than real (Solbrig, 1991). In addition, it is necessary to stress that in cases where there may be some functional redundancy, the presence of a variety of organisms able to perform the same task will contribute to the resilience of the ecosystem and its ability to withstand perturbations (Perry *et al.*, 1989). In the longer term the elimination of apparently redundant or rare species may reduce the capacity of a healthy system to respond through diversification to future major perturbations (Lovelock, 1992).

55 Certain species, for example most forest trees, are "structural" species in the sense that because of their size and structural complexity they strongly influence the local environment and support large numbers of interstitial species such as insects and bark- and leaf-inhabiting fungi (including lichens) and algae. Some species, not necessarily obvious components of the ecosystem, exercise a disproportionate effect on other species or on ecosystem function and have been called keystone species.

They can be grouped into three classes: (a) keystone predators and herbivores, (b) keystone mutualists, and (c) keystone resource species (Solbrig, 1991).

Keystone resource species

56 It has been suggested that high species richness in tropical high-rainfall ecosystems improves the efficiency of capture, storage and recycling of nutrients, partly due to the diversity of root systems and associated mycorrhizal fungi, under conditions where leaching would otherwise lead to nutrient depletion (Lugo, 1988). About 85% of the world's vascular plants form mycorrhizas with fungi and for many of these the association is obligatory to enable them to absorb mineral nutrients essential for growth (Read, 1991). Other fungi and bacteria are involved in breaking down the large amounts of plant debris on forest floors and recycling the scarce nutrients, fungi having the dominant role in the degradation of organic nitrogen, sulphur and phosphorous in soil (Wainwright, 1988). Bacteria perform fundamental roles in the geochemical cycles of nitrogen and sulphur in particular, with unique roles in nitrate/nitrite interconversions and the fixation of atmospheric nitrogen (Trüper, 1992; see also *para* 58). Amongst invertebrates, termites (Lee & Wood, 1971) and earthworms (Lavelle, 1988) both play an important role in nutrient cycling in tropical soils.

57 Microbiotrophic nematodes are one of the most widespread and abundant, yet much neglected, animal groups. In tropical forest soils they are important primary consumers and in turn provide food for larger invertebrates. Their numbers can reach 1.9 million per square metre (Groombridge, 1992).

58 The cyanobacteria (or blue-green algae), are an important group of photosynthetic prokaryote organisms, constituting at least five orders and with a huge range of morphologies and ecologies (Whitton, 1992). Much of the earth's original atmospheric oxygen was evidently formed by such organisms and they are still important producers of oxygen in the oceans. It is likely that the photosynthetic bodies (chloroplasts) within all higher plants and green algae evolved from prokaryotes of this type.

59 Many cyanobacteria are resistant to water stress and/or to high temperatures and are, therefore, able to survive in extreme environments such as deserts and highly saline pools. That cyanobacteria are able to fix atmospheric nitrogen makes them an important component of communities where availability of nitrogen is limiting to plant growth. Taxonomic problems in these bacteria are considerable (Whitton, 1992). Often single morphological characters have been used for characterizing taxa in earlier works, yet these may vary according to environmental conditions; some confusion has arisen from the assignment of arbitrary limits to a continuous range of variation. There is a need for more research on the theoretical basis of cyanobacterial species and genera requiring the integration of morphological work and molecular studies with field populations and laboratory cultures.

Keystone predators, pests and herbivores

60 Keystone predators and herbivores, parasites and pathogens are those that permit the maintenance of a balance between competing organisms by reducing the abundance of the dominant competitor and preventing competitive exclusion (Solbrig, 1991). In tropical dry forest in Costa Rica certain highly prolific trees are kept at low density by the effect of small bruchid seed beetles which all but wipe out the seed crop (D. Janzen, pers. comm.). Neotropical leaf-cutting ants of the genus *Atta* have been estimated to consume between 12 and 17% of total leaf production (Cherrett, 1989). In a parallel manner, bacterial, fungal and viral pathogens will reduce the vigour of trees and other green plants in natural as well as

agricultural systems - yet basic information on the role and dynamics of pathogens in natural ecosystems is meagre (Burden & Leather, 1992) although important contributions are starting to appear (Alexander, 1992). Nevertheless, it is inevitable that the removal of such keystone herbivores or pathogens will radically alter the species composition and structure of a whole forest.

61 Poignant examples of this phenomenon are documented in certain parasitic *Hymenoptera*. These have been shown to be important and perhaps essential in preserving ecological balance and maintaining biological diversity in terrestrial ecosystems (LaSalle & Gauld, 1992). *Hymenoptera* interact with other insect species as predators and parasitoids more than any other insect order, accounting for up to 57% of predation on other insects and themselves constituting up to 44% of insect prey (LaSalle & Gauld, 1993). Wasp parasitoids are widely used to regulate the populations of their plant-feeding hosts in biocontrol programmes and there is considerable evidence that they exercise a similar function in natural ecosystems (LaSalle, 1993).

62 Most evidence of the effectiveness of this interaction comes from studies of managed systems where parasitoids have been removed and the population of the host monitored. Most often this has occurred in cases of accidental importation of plant-feeding insects without their associated wasp species (Bagine *et al.*, 1993). Widespread and serious damage follows which may threaten local extinction of the plant concerned. In the case of the cassava mealybug, accidentally introduced to Africa, damage estimated at US\$ 250 million annually was halted by the introduction of a single encyrtid wasp, *Epidinocarsis lopezi* (Norrsgard, 1988).

63 It is also argued that the extinction of one or more parasitoids which constitutes the key mortality factor for the dominant insect species feeding on a plant may unleash a "cascade effect" (LaSalle, 1993), starting with the death of the plant population as a result of the explosion of the host insect pest freed from restraint. This entails also the death of some or all of the other specialist phytophagous species directly dependent on the plant and, in turn, their specialized hymenopterous parasitoid species and any hyperparasitoids (also wasps) -- as well as other macro- and microorganisms dependant on it. In a forest in Borneo, almost 60% of the chalcidoid wasp species were found to be represented by a single individual and the average abundance for all of the 1455 species present was only 2 individuals (Stork, 1988). Such rarity is not incompatible with keystone status because the hosts of these wasps are being maintained at very low levels by the highly effective searching behaviour of the wasps. However, such low numbers must make the wasps vulnerable to local extinction by environmental perturbations, leading to upsurges of their hosts (LaSalle, 1993). The importance of such rare species as a potential pool of agents for biological control in managed systems has been emphasized by Myers *et al.* (1989).

64 It is also pertinent to stress that the introduction of a serious pathogen into natural ecosystems can be devastating. The cases of Chestnut Blight in North America caused by *Cryphonectria parasitica* and of Dutch Elm Disease in Europe due to *Ophiostoma ulmi* are well-known. More serious from the conservation standpoint is the lawn-mower effect that *Phytophthora cinnamomi* is having on native Australian forests (Alexander, 1992). An aspect of the protection of nature reserves must be to have personnel able to be both vigilant in minimizing the risks of introduction of such serious pathogens, and able to recognize and eliminate them before they become so well-established that the situation is irretrievable.

Keystone mutualists

65 Mycorrhizal associations are likely to be at least as important in tropical forest ecosystems as they are in temperate ones. More detailed data on these associations

and their relation to forest regeneration are required, although the information available in relation to temperate forests in particular has developed rapidly in the last 10-15 years (Read *et al.*, 1992). Even less is known of the relations between plants and endophytic fungi, species living inside healthy plants forming "mycophyllas", but they can confer distinct advantages on their hosts through imparting insecticidal properties in particular (Clay, 1992).

66 Gut-inhabiting mutualistic bacteria and fungi are essential to the success of most insects and other plant-feeding animals, enzymes from the microorganisms being essential to enable them to convert celluloses and other compounds into simple sugars that can be absorbed through the gut linings (Martin, 1987). Ruminants require bacteria, specialized anaerobic fungi and other organisms, and some termites utilize bacteria and protozoa as well. The Old World *Macrotermitinae*, cultivate fungus gardens of the mushroom genus *Termitomyces* on a mulch of plant material and feed on the fungus (Batra & Batra, 1979). A range of wood feeding beetle families (*Cerambycidae*, ambrosia beetles, bark beetles) depend on fungi in rotting wood or feed on fungi directly. The extent of mycophagy in insects is spectacular (Hammond & Lawrence, 1989), and in a major study in Sulawesi about half the beetle species were fungus feeders or probably seeking fungi in wood (Hammond, 1990). The extent of specificity is, however, obscure. Fungi play a mutualistic role in ambrosia galls formed by gall midges of the *Cecidomyiidae* which have evolved special structures for the transport and inoculation of the fungus strains (Bisset & Borkent, 1988).

67 An important association exists between earthworms, plant roots and microorganisms which break down organic matter in the soil. The earthworms secrete mucus which help microbes to metabolize the organic matter, releasing nutrients which are then available for uptake by plants. The system works more effectively at tropical temperatures and may be important in regulating plant species diversity (Lugo, 1988).

68 Pollination systems are dominated by the bees and flower/bee associations are critical to the maintenance of green plant diversity. As with the parasitoids, extinction of a pollinator may produce a cascade effect beginning with the loss of the plant and any species directly dependent on it. Males of euglossine solitary bees are the major or exclusive pollinators of most forest orchids, but the activities of female bees are directed to a range of other plant species in different strata and forest types. The loss of orchids due to habitat degradation or collecting could, therefore, have a disastrous effect on the bees utilising their pollen and nectar and indirectly on other plant species pollinated by the bee. If the plant in question is a keystone species than a variety of other species are endangered as a result (LaSalle & Gauld, 1993). In fact euglossine bees are the principal pollinators of Brazil nuts (*Bertholletia excelsa*) an important forest crop for indigenous people in the Amazon basin rain-forests (Prance, 1976). A study of meliponid bees in a reserve in South East Asia found that bees nesting up to 1km from the reserve boundary were exclusively collecting pollen from plantations outside the reserve. This has serious implications for trees in small reserves (Appanah, 1987).

69 The most striking example of such a pollination association involves the fig wasp family, *Agaonidae*, which are the sole pollinators of most of the 800 species of *Ficus* (LaSalle & Gauld, 1993). Figs have been recognized as a keystone resource critical to the survival of forest primate populations during the dry season (Solbrig, 1991). Terborgh (1986), describing the range of mammal and bird species using figs as a food resource in a Peruvian rain-forest, noted: "Figs sustain a high diversity of species ranging in size from spider monkeys (10 kg) to tanagers (20 g) and constituting up to 60% of the frugivore biomass ... Subtract figs from the ecosystem and one could expect to see it collapse". LaSalle and Gauld (1993) comment that neither of the foregoing authors appears to have considered the

critical importance of the agaonids to fig diversity or the devastating cascade effect their loss would precipitate.

70 Another class of mutualistic associations between plants and insects concerns the dispersal of plant seeds by ants, termed myrmecochory. Such associations result in increased seedling recruitment by wider dispersal reducing competition and burying seeds below ground, protected from fire and predators and provided with nutrient enriched soil (Holldobler & Wilson, 1990). Plants may provide special edible structures on seeds (elaiosomes) which attract ants to carry them back to their nests. It has been estimated that the seeds of 35% of all herbaceous plants are dispersed by ants (Beattie, 1985). The indigenous ant fauna of the Cape region of South Africa is being displaced by an introduced species of *Iridomyrmex* which transports seeds less far and leaves them exposed instead of burying them. This is believed to be causing a decline in seedling recruitment among the rare endemic *Proteaceae* of the Cape fynbos community (Bond & Slingsby, 1984).

71 Many plants are protected by ants from attack by other insects and even from competition from seedlings and climbing vines. Some plants have hollow stems or bulbous thorns which ants use as shelters (domatia), depositing waste material from which nutrients may be absorbed by the plant. Unoccupied plants have been shown to suffer disadvantage compared to their tenanted neighbours and many attract the ants by the provision of food in the form of extra-floral nectaries and a variety of small removable structures rich in glycogen, a carbohydrate normally associated with animals (LaSalle & Gauld, 1993).

72 Some algae and cyanobacteria also have keystone roles in lichen formation. A wide variety of fungi that form lichens do so with a very restricted number of photosynthetic partners. Indeed there are around 500 lichen-forming genera associated with some 35 algal and cyanobacterial ones (Hawksworth & Hill, 1984). If genera such as *Cephaleuros*, *Nostoc*, *Phycopeltis*, *Scytonema*, *Trebouxia*, or *Trentepohlia* were eliminated from a tropical or other ecosystem, not only would the lichen-forming fungi not produce lichens but the invertebrates and other organisms dependent on lichens would be endangered.

ENVIRONMENTAL BIOINDICATORS

73 In any plan to conserve biodiversity in nature, some measure of the health of the area being protected is essential. Bioindicators, organisms expressing particular symptoms or responses indicative of changes in some environmental influence, usually in a qualitative manner, can assist in this vital role. They are not, however, to be confused with "biomonitors", species in which changes in numbers or distribution over time are studied and compared with baseline data (Hawksworth, 1993b). Most work on bioindication has been undertaken in Europe and North America (e.g. Jeffrey & Madden, 1991), but the methods are equally applicable in tropical situations. CABI sees tremendous potential for the application of appropriate bioindicator technology in the conservation, assessment and monitoring of ecosystem health in the tropics. CABI and Natural History Museum staff assisted in a training course in the *Application of Bioindicators in the Conservation of Biodiversity* arranged by the M.S. Swaminathan Foundation in Madras in May 1992, with sponsorship from ODA.

74 Bioindicators have applications in the detection and assessment of air and water pollution, climatic and environmental change, ecosystem continuity, and soil health. Diverse groups of organisms have been used, but ideally they should (Hawksworth, 1992a):

- Show a prompt and accurate response to a particular discrete cause of perturbation.
- Reflect some aspect of ecosystem function.
- Be components in the lower parts of food-chains, -pyramids or -webs of macroorganisms.
- Be amenable to the application of portable and standardized sampling methods operable by non-specialists.
- Have widespread distributions and be expected in the area to be studied from knowledge of their biogeography and ecology.
- Include species characteristic of different degrees of perturbation to enable at least qualitative measurements to be made.
- Be readily identifiable to the level necessary for bioindication in the field with minimal equipment (e.g. a hand lens).

Bioindication of Habitat Disturbance

75 The use of bioindicators in this way can indicate when some key environmental or disturbance factor is coming into play *before* the ecosystem starts to collapse irretrievably. For example, it is now known that the frequency of ectomycorrhizal fungal fruit-bodies would have indicated that something was seriously amiss with the central European spruce forests 10-15 years before their sudden death caused newspaper and television headlines (Arnolds, 1991).

76 Further, some easily surveyed organisms, of which the best examples are lichenized fungi, are particularly sensitive to forest disturbance and can be used to indicate the extent of disruption through forest clearance and selective felling (Rose, 1992). While much (but not all) such work has been in temperate deciduous forests, scattered publications from South East Asian (Wolseley, 1991) and Australian (Kantvilas *et al.*, 1985) rain forests, and field observations leave no doubt that the technology is widely applicable in tropical forests (D L Hawksworth, pers.comm.).

77 Recent work on forest insect faunas, mainly carried out in rainforests in South East Asia has focussed on the inventory of the enormous and complex faunas involved. While more comparative data on species composition and diversity as between disturbed and undisturbed forest are needed, it is clear that certain arthropods can also serve as bioindicators of forest disturbance (Holloway & Stork, 1991). Ants (*Formicidae*) in forest tree canopies, and Springtails (*Collembola*) and mites in leaf litter and soil, have been shown to be major components of natural forest faunas in terms of individuals, biomass, or both (Stork & Brendell, 1993). The proportion of tree-feeding versus herb-feeding families of *Lepidoptera* has been advanced as potential indicators of forest disturbance (Holloway & Barlow, 1992). Other promising groups include beetles (Hammond, 1990) and spiders (Russell-Smith and Stork, 1993).

78 Earthworm and scarab beetle species numbers are markedly lower in agricultural soils than in nearby natural communities (Lee, 1991; Nestel *et al.*, 1993). Various other components of the soil fauna such as termites, myriapods, mites and springtails are potential indicators of soil health (Paoletti *et al.*, 1991) but there is a lack of baseline information on the role of these organisms in natural

communities and food chains and the effects of specific changes induced by man on their diversity.

Bioindication of Pollution

79 In temperate regions, lichens, yeasts and to a more limited extent other leaf surface fungi have been used as *in situ* indicators of air pollution, especially of sulphur dioxide levels, but are also of value in monitoring fluoride, heavy metal, radionuclide and other pollutants (Nash & Wirth, 1988; Richardson, 1992; Bates & Farmer, 1992). Lichen bioindication of air pollution has an enormous literature, and while most work is from temperate regions and increasing number of studies from the tropics leave no doubt that the technology is widely applicable. Methods using colour charts have been used successfully with school-children demonstrating the feasibility of use by non-specialists.

80 Free-living nematodes have potential as indicators of ecosystem health in such areas as water pollution and soil quality (van der Wal and de Goede, 1988). However, their minute size and complex interactions with plant roots and microorganisms combined with the difficulties of culture, make them difficult to study.

81 In aquatic ecosystems macroinvertebrates have been widely used as bioindicators in the temperate zones of the Northern Hemisphere. Suitable groups include the larvae of many insects (mayflies, stoneflies, caddis flies, midges). Methods have been reviewed and standardized by Lenat (1988), and Maher & Norris (1990) discuss the application of particular indicators to specific problems of water quality. As in the case of lichens, charts and kits suitable for use by public health officials and school children have been developed (WATCH, 1991).

82 The intensity of infection with *Monogenea* on the gills of fish increases in highly polluted water as compared with regions of unpolluted water. Conversely, the incidence of *Acanthocephala* in catfish in river water polluted by domestic and industrial waste in Canada was lower than elsewhere because of toxic effects depleting the invertebrate intermediate hosts. Prevalence and intensity of infection with such parasites are, therefore, potentially useful in assessing the extent of pollution in aquatic environments (Khan & Thulin, 1991).

83 Various algae, and also cyanobacteria, can respond in a dramatic manner to pollutants in water (Yasuno & Whitton, 1986) leading to algal blooms on freshwater lakes and red tides; in some cases highly toxic products fatal to mammals can be formed by certain dinoflagellates and cyanobacteria. These minute organisms, and also diatoms (Round, 1991), have value as bioindicators but their application is hindered by the need for critical sampling and high-power microscopic examination.

Bioindication of Climate Change

84 It has been suggested that insects may be used to monitor climatic change (Holloway & Stork, 1991). Long-term sampling of moths on Norfolk Island indicated changes in the relative abundance of particular species correlated with rainfall.

85 Changing distribution patterns of other species easily identified in the field, for example certain lichens, have been suggested to also have potential to contribute to the assessment of climate change (Gilbert, 1989).

Biosystematics and Sustainability

86 Biosystematics can contribute to the sustainable use of natural resources in a variety of ways. In the case of microorganisms and invertebrates, we have identified eleven cases where improved biosystematic knowledge can contribute to sustainable development.

NITROGEN FIXATION

87 Nitrogen is the nutrient most limiting agricultural productivity. The annual global fixation of nitrogen by bacteria has been estimated at 240 million metric tons (240 Tg) (Trüper, 1992). The production of leguminous crop plants for their own sake and as green manure depends on the presence of nitrogen-fixing *Rhizobium* bacteria. In rice fields the floating fern, *Azolla*, has a similar mutualistic association with cyanobacteria (Giller & Wilson, 1991), and cyanobacterial lichens can fix significant amounts of nitrogen in moist forests (Boucher & Stone, 1992). Considerable attention has been directed to the selection of the most efficacious *Rhizobium* strains for inoculation into leguminous crops and this has been a primary focus of the MIRCEN network (*para* 16, 90). More efficient strains of these microbial mutualists can increase nitrogen fixation, and so agricultural production, markedly (Sprent & Sprent, 1990), not only in crop plants themselves, but also as mutualists of "green manure" intercrops.

88 In addition, free-living nitrogen-fixing bacteria, such as *Azospirillum*, and *Azotobacter*, can be bulked up with limited facilities and inocula distributed to small farmers to use instead of commercial fertilizers. This is practised, for example, at the Tamil Nadu Agricultural University at Coimbatore in India (D.L. Hawksworth, pers. comm.).

89 Yet despite their potential, new nitrogen-fixing bacterial species are still being discovered, for example two recently found in association with mangrove roots (Holguin *et al.*, 1992), isolations from uncultivated legumes have not been assessed, and the level of systematic knowledge of cyanobacteria is currently abysmal (*para* 59; Whitton, 1992).

90 Although a co-ordinated compendium of the *Rhizobium* strains maintained in 73 microbial culture collections is available (McGowan & Skerman, 1986), there is no coordinated plan for the isolation, preservation, and delivery of the full range of nitrogen-fixing bacteria (including cyanobacteria) to scientists in less-developed countries.

91 The benefit of improved utilization of nitrogen-fixers to sustainability is that the crop yield per unit area can be increased without dependence on chemical fertilizers, the supply of which can be both costly and erratic.

MYCORRHIZA FORMATION

92 Mycorrhizal associations can enable a wide variety of plants to grow more vigorously than without them by ensuring a supply of the nutrients that most limit their growth (Read, 1991). In addition, they may enhance nitrogen fixation by plant-bacterial mutualisms, and may also transport fixed nitrogen to non-fixing

plants via fungal hyphae from other plants. In cropping systems nitrogen fixed by soybeans and transported to maize, significantly increasing the growth of both (Allen, 1991). Trappe (1977) noted that up to 2,000 species of fungi could associate with a single host tree and he hypothesized that multiple infection conferred advantages, in addition to providing a larger surface area for absorption, because each species can acquire different resources and tolerate different conditions, as well as conferring resilience to the ecosystem (*para 54*).

93 Some mycorrhizal fungi may provide protection against some pathogenic fungi, for example on pine trees, *Pinus sylvestris* (Kowalski, 1980). There is a need for much further research on the significance of mycorrhizal diversity and the interactions between mycorrhizas, nitrogen-fixing bacteria, their host plants, and other plants.

94 While considerable progress in the selection and inoculation of the most effective ectomycorrhizal strains has been made in commercial forestry, especially of conifers in temperate regions, the level of knowledge of the relative importance of different species in tropical ectomycorrhizas, for example of *Dipterocarpaceae*, is almost non-existent and inoculation is by moving soil (Smits, 1992). Progress in this field is hampered by a grossly inadequate taxonomy for the mushrooms involved -- a large proportion of the species being undescribed.

95 In the case of vesicular-arbuscular endomycorrhizas, which are of major importance in tropical forest trees and many herbaceous plants, relatively few species are currently recognized, primarily on the basis of their micromorphology. Studies on *Terminalia* plantations in the Ivory Coast supported by ODA (contract R4319) revealed 41 spore types, those of an unidentified *Glomus* predominating (Wilson *et al.*, 1992). Controversy surrounds species concepts in the *Endogonales*, the principle group of fungi involved (Morton *et al.*, 1992), and there is limited experimental work as regards host-specificity, strain differentiation, and biochemical/ molecular relationships. Techniques for the culture of these fungi are also in need of development to enable the potential of these fungi to be realized.

96 Improved knowledge of the biosystematics of mycorrhizal fungi and their host specificity would enable the selection and inoculation of strains to be placed on a secure scientific base. Molecular techniques involving DNA amplification from hyphae infected roots and comparing these with fruit bodies in the vicinity have considerable promise in advancing expertise in this respect. This has the potential not only to improve the productivity of plantations (including those of introduced trees) but also to facilitate the re-establishment of native species.

MAINTAINING SOIL FERTILITY

97 Diverse microorganisms and invertebrates contribute to the maintenance and enhancement of soil fertility. The importance of termites and earthworms in nutrient cycling in natural ecosystems has already been mentioned (*para 66-67*). Termites are estimated to ingest 25-70% of litter in Old World tropical savannas (Lavelle, 1988). The litter is decomposed and the excreted nutrients are incorporated into the soil. The majority of ants and termites probably increase carbon and nutrient levels in soils, especially nitrogen, phosphorous and potassium, as well as exchangeable magnesium and calcium (de Bruyn & Conacher, 1990).

98 Termites (like earthworms) play an important role in aerating soil and in creating fine textured soils. Some tropical soils are known to have been created largely through their activity (Wielemaker, 1984). Clearance of natural plant communities for agriculture may produce major changes in the soil fauna leading to compaction, erosion and loss of nutrients by leaching. In Queensland the accidental

introduction of the earthworm *Pontoscolex corethrurus* in sugar-cane plantations (originally forested) led to striking improvements in soil structure and incorporation of organic material (cane trash) (Lee, 1991).

99 Practices such as mulching, interval cropping and use of cover plants may provide more stable conditions in managed environments, suitable for the maintenance or restoration of soil faunal diversity (Lavelle, 1988). However, the selection of appropriate species of earthworms for soil amelioration in different ecosystems is hampered by the lack of ecological knowledge of tropical species, of which only about six have been studied (Lee, 1991).

100 In general the role of invertebrates other than termites and earthworms in tropical soils is poorly known, especially in the case of microfauna (including nematodes) and mesofauna (Lavelle, 1988). There is therefore a great need to investigate the components of such faunas, with more attention to species other than the most dominant or prominent species, and to assess the effects of management practices on them (Lavelle, 1988; de Bruyn & Conacher, 1990).

101 However, it is the microorganisms that constitute the major living biomass in soils, exceeding that of the invertebrates. They exceed the faunal groups by a factor of 400 in temperate soils and by an unknown amount in tropical ones (Lee, 1991). Amongst the microbial groups, it is the fungi that are predominant (Lynch & Hobbie, 1988). Yet although the literature on soil microorganisms is substantial, the level of knowledge at the functional level is minimal. This is in no small measure due to the problems of identifying which of the various fungi and other microorganisms that can be isolated into culture are active in the soil -- and also uncertainty with respect to uncultured species that may be active. In the case of the fungi, conclusions are difficult to draw because most studies are from agricultural or other disturbed soils. Assumptions that there is little difference between geographical areas (e.g. Gams, 1992) are suspect due to both restricted isolation methods and inadequate habitat sampling, to judge from isolates received at IMI.

102 Molecular approaches have the potential to make major contributions to our knowledge of microbial ecology in soil, but a massive investment is likely to be required before exploitable methods of improving soil fertility result.

WASTE UTILIZATION

103 Agricultural and other organic wastes from industry are a major problem in the developed and the developing countries. Fungi have particular potential in the transformation of wastes by upgrading them into food. Bagasse, coire and paddy straw can be mixed with urea and used to cultivate edible mushrooms, particularly *Pleurotus* species. In addition, cellulolytic fungi such as *Trichoderma* can upgrade cereal wastes so that they are usable as animal feedstuffs or organic additives to soils (Kelley, 1992).

104 Although a considerable number of fungi have been grown commercially for human consumption, especially in Asia, only in a few cases has research focussed on the selection of the most productive strains. Attention can also be increasingly focussed on species found to be particularly suited to local conditions, as in the case of *Coprinus castaneus* on sugar-cane waste in Mauritius (Desai & Peerally, 1992). Because of difficulties in preservation, other than by liquid nitrogen storage, edible mushrooms are rather poorly represented in most fungal culture collections, and there have been few concerted attempts to develop comprehensive collections; those at the Horticulture Research International in Littlehampton and the Tottori Mycological Institute in Japan are notable exceptions. This restricts the scope for experimentation on local wastes.

105 Effective biomass conversion and detoxification requires careful research, and prospects remain limited by the lack of basic information on the genetics and other aspects of the microorganisms involved (Sawyer, 1984). Despite its huge potential in waste recycling, the taxonomy of *Trichoderma* remains in a most unsatisfactory state. Communication has been hindered as a result of both the different applications of names, and further by some of the "species" currently recognized encompassing a wide range in variation in not only cellulolytic activity but also secondary metabolite production. In view of the importance of these fungi, the International Commission on the Taxonomy of Fungi (ICTF) has established a group of specialists to start to rectify this position, but major progress is unlikely in the short-term without special funding.

106 Such technologies are of particular appeal in countries where food and resources are scarce, yet their development is only in its infancy. Edible mushroom production from wastes is amenable to small-farmer production from locally produced "spawn" inocula, and can contribute to sustainability by both increased food production and the reduction of polluting wastes.

POLLINATION

107 Effective pollination is the key to a high percentage of fruit and seed production in all insect pollinated crops, as well as in natural communities (*para* 68-69). As much as 30% of all human food comes from insect-pollinated plants (O'Toole, 1993). In the case of figs (*para* 69), pollination is effected solely by specialist wasps. The value of improved pollination in a single crop can be enormous. The importation of the weevil *Elaeidobius kameronicus* from West Africa into Malaysia to pollinate oil palm, was estimated to be worth US\$ 115 million per annum in increased production and reduced costs of hand pollination (Anon., 1982).

108 In the case of oil palm, the introduction of the pollinating weevil was only possible as a result of painstaking critical taxonomic investigations of the various insects associated with the trees. It is remarkable that for such an economically important crop the identity of the pollinating insects remained obscure until the late 1970s.

PEST MANAGEMENT

109 Clear species concepts are crucial to pest management, and limitation of the damage caused by bacteria, fungi, insects, nematodes and viruses can contribute significantly to sustainability by improving the yield per unit area. This is especially so when it is recognized that up to half of the crops grown on Earth are lost through the pre- and post-harvest ravages of such organisms.

110 The importance of diversity in relation to pest status can be well illustrated by the fruit flies (*Tephritidae*), a group of about 4,000 species, mostly feeding on flowers or fruits. Of these about 250 species are known to cause economic damage world-wide (White & Elson-Harris, 1992). Estimates of the cost of potential losses in Australia in the absence of control exceed A\$100 million annually (Anon, 1986). Dowell & Wange (1986) listed eight species that are a major threat to California and estimated that if established widely they would cause losses of US\$910 million and cost US\$ 290 million to control. Not surprisingly there are strong groups of taxonomists working on this relatively small group of insects in both Australia and the US.

111 Plant parasitic nematodes have been estimated to destroy 7-15% of the annual crop production of the USA (Poinar, 1983). Root-knot nematodes (*Meloidogyne* spp.) are an especially damaging group throughout the tropics, leading to losses ranging from 15 to 48% on a range of crops, including tomatoes, common beans, yam, papaya, coffee, melon, carrot and cotton (Sasser, 1979). Some free-living nematodes associated with crop plants may play beneficial or destructive roles in different circumstances. Some species that feed on bacteria may also damage roots and others which attack pathogenic root fungi may on another occasion attack mycorrhizal fungi (Groombridge, 1992).

112 Plant pathogens have received considerable attention from systematists, and major compilations covering tropical plant bacteria (Bradbury, 1986), fungi (Holliday, 1980) and viruses (Brunt *et al.*, 1990) exist. However, considerable difficulties remain where morphologically indistinguishable fungi, and bacteria not separable by regular "bacteriological" methods, cause diseases in different crops. In order to provide systems of communication, "special forms", "pathovars" and "races" have been distinguished. These terms are unfortunately not used consistently within different genera, cannot readily accommodate the level of genetic variation encountered -- especially when "gene-for-gene" coevolution is in progress (Parleviet, 1986). The whole basis of the concepts of species and infraspecific categories merits revision (Brasier & Rayner, 1986).

113 Such a clarified taxonomy is urgently needed in order to enable virulent strains to be recognized with confidence and risk assessments to be soundly based. The major advances in biochemical and molecular approaches of the last decade have provided tools to elucidate such complex situations in a more fundamental way than was hitherto possible. Progress is starting to be made in some critical groups, and IMI currently has contracts from the Natural Resources Institute (NRI) to examine such problems in *Fusarium oxysporum*, *Ganoderma*, and *Rhizoctonia solani*. However, in view of the scale of the problem in these cases, and in genera such as *Cercospora*, *Colletotrichum* and *Puccinia*, substantial investments are needed in order to examine the large numbers of strains from a wide variety of hosts necessary to achieve lasting taxonomies.

HUMAN AND ANIMAL DISEASES

114 Human and animal diseases are relevant to sustainable development as human populations must be healthy to work in an optimal way, and the productivity of livestock will also be reduced by disease. In addition, if developing country conditions are particularly risky to humans, potential revenue-bringing tourists will be deterred from otherwise attractive regions. Some indication of the importance attached to microbial groups in human health is indicated by the pattern of the US National Institute of Health (NIH) annual research expenditure, currently US\$ 280 million on viruses, 90 million on bacteria, 50 million on parasitology, and 10 million on fungi (D.W. Denning, pers. comm.).

115 Helminth parasites of man and his domestic animals cause enormous losses, both financially and more importantly in terms of human lives. For example, it is estimated that 900 million people may be infected with hookworms, of whom 50-60,000 die each year, while of the 30 million estimated cases of onchocerciasis, 20-50 thousand die annually (Groombridge, 1992). Helminths cause serious losses to domestic livestock and may also affect rare game animals. They are common in marine and freshwater fish and may be a hazard in fish farming.

116 Helminth life cycles are often complex and can involve one or more intermediate hosts, often invertebrates. Taxonomic studies are required to establish the causes of variation within species in relation to drug treatment and

pathogenicity. Variability in responses to treatment, drug resistance or pathogenicity may indicate the presence of more than one species or different strains.

117 The relationship between tropical diseases and their vectors can be complex and resolvable only after painstaking biosystematic investigations. For example, problems in the identification of the *Simulium damnosum* complex of blackflies hampers the understanding of the spread of onchocerciasis (Muller & Baker, 1988).

118 The application of microorganisms, especially bacteria, to the control of blackflies and mosquitos (de Barjac & Sutherland, 1990), must also be founded on a sound taxonomy for both target vectors and potential control organisms.

119 Dermatophytes (skin-invading) and the most generally encountered opportunistic fungi have been extensively investigated, but major taxonomic problems remain in some groups. For example, asexual *Trichophyton* ring-worms where accurate identifications are needed to assess man/animal transmission risks. It is also remarkable that the relationships of *Pneumocystis carinii*, causal agent of a fungal pneumonia involved in the deaths of about 80% of AIDS victims, have only recently been determined (Wakefield *et al.*, 1992) and that only now can progress be made in endeavouring to limit infections.

120 Food safety is of major concern throughout the world, and involves a consideration of bacteria, fungi (including mycotoxin-producers and yeasts) and certain protozoa. In the case of the fungi, in order to assess whether a particular crop or cargo is fit for human consumption, it is often necessary to be able to discriminate between superficially rather similar species of mycotoxin-producing genera such as *Aspergillus*, *Fusarium* and *Penicillium*, and also to recognize other fungi that can also pose risks. As species concepts have been revised in many food-spoilage fungi, taking note of growth characteristics, biochemical and ultrastructural features, good correlations with toxin production and other secondary metabolites have been found (Frisvad & Filtenborg, 1990). The application of similar approaches to other genera, for example *Chaetomium*, would greatly facilitate risk assessment when food is invaded by them.

NATURAL ENEMIES

121 In many cropping systems, especially perennial crops with relatively low disturbance, there is a fauna of natural enemies feeding on the crop pests present in the crop. The more complex the cropping system the more likely it is to contain the elements needed for successful establishment and survival of natural enemies. The system can be manipulated to encourage predatory syrphid flies or parasitic wasps by providing nearby sources of nectar for adults (Waage, 1991a).

122 In rice fields a diverse group of spiders have been shown to play an important role in controlling brown plant hopper (*Nilaparvata lugens*). Their numbers and effectiveness are drastically reduced by insecticidal treatment which caused an upsurge of the pest (Holdom *et al.*, 1989). The presence of predatory mirid bugs which are less susceptible to insecticide gives some continuing control. They also provide an alternative food source for the spiders. The effectiveness of predators is significantly improved by the use of resistant or moderately resistant rice varieties (Kartohardjono & Heinrichs, 1984). The provision of refuges of straw in harvested rice fields significantly increases survival of natural enemies which could recolonise fields when the next crop is established (Shepard *et al.*, 1989). Roger *et al.* (1991) have pointed out that raised general diversity per se is insufficient to suppress pests. It is the precise make-up and trophic linkages of the predatory fauna which are important. More knowledge of these aspects are needed.

123 There is beginning to be evidence that some rice diseases are kept under some degree of natural control by antagonistic bacteria. *In vitro* experiments with *Fusarium* showed that 60% of rice field bacteria had some inhibitory effect on its growth. High levels of control have been obtained in nursery plots by bacterial inoculation (Roger *et al.*, 1991). The injudicious use of fungicides in perennial crops may disturb natural systems of soil and plant surface microorganisms which hold in check important pathogenic diseases such as coffee berry disease in Kenya (Waller, 1991). In order to be able to manipulate such systems in future we need to develop a better understanding of the functional diversity of organisms involved in pathogen inhibition.

BIOCONTROL

124 Biocontrol can make a particularly important contribution to sustainability through the use indigenous and introduced natural enemies to provide on-going control of pest populations without the use of insecticides or herbicides. The pool of organisms from which useful control agents may be drawn has been estimated to consist of more than 50% of all the species on earth (Waage, 1991b). Over 500 insect natural enemies have been established for control of exotic insect pests, with a success rate of about 40% (Waage & Greathead, 1988). Among the range of natural enemies, the parasitic wasps or parasitoids, which attack other insects, have been estimated to contain 10% of all animal species (Askew, 1971). Parasitoids have the ability to react to increases in host population density by increased searching efficiency, becoming less effective as the host population declines. This allows them to regulate host numbers within certain limits without disastrous population explosions or crashes (Waage, 1991b).

125 The benefits of successful biocontrol programmes are enormous. Annual savings resulting from the biocontrol of cassava mealybug in Africa amount to US\$ 250 million annually, with a benefit-cost ratio of 149:1 (Norrgard, 1988). Similar savings are known from other programmes, but perhaps even more important are the environmental savings resulting from reduced pesticide usage (LaSalle, 1993).

126 Sailer (1983) estimated that 11 potential new pests enter the United States each year of which seven are liable to be injurious. Throughout the world international movement of insects and the creation of habitats newly favourable to pests in the course of agricultural development and land degradation are constantly creating novel pest problems. Many of these are insects of no known importance in their original environment. It has been pointed out (Waage, 1991b; LaSalle, 1993) that since we cannot predict what species may become pests in future, the maintenance of a large natural reservoir of parasitoid diversity is crucial for future biocontrol programmes.

127 Successful biocontrol of introduced weeds has been achieved using phytophagous insects with very specialized feeding habits. White & Elson-Harris (1992) document 22 species of tephritid fruit flies of actual or potential value for biocontrol of which perhaps half have proved to be useful in control programmes. Accurate taxonomy has played an important role in the selection of these agents (White, 1991).

128 The rich global biodiversity of bacterial, fungal and viral pathogens of insects and other pests remains a little-exploited resource for biocontrol, although the recognition of its importance has increased dramatically in the last decade (Waage, 1991b). Some particularly virulent microbial pathogens of insects have been mass produced and formulated as biopesticides. In particular, strains of *Bacillus thuringiensis* have been widely used against moth caterpillars, biting fly larvae and beetle grubs. Strains of entomopathic fungi such as *Beauveria* and *Metarrhizium*

are also being developed against a range of pests including locusts. In the case of locusts, a major international programme involving the isolation and characterization of fungal strains from grasshoppers and locusts has been conducted in which both orthopteran and fungal taxonomy have played key roles.

129 A number of microorganisms have been identified as biocontrol agents against economically important plant parasitic nematodes. Of these, the nematophagous fungi, *Verticillium chlamydosporum*, *Nematophthora gynophila* and *Hirsutella rhossilliensis*, together with the bacterium *Pasteuria penetrans* have proved the most promising (Davies *et al.*, 1991). Entomopathogenic nematodes, particularly the soil-dwelling neoaplectanids and steinerematids, have great potential as biocontrol agents and several species are already in commercial production (Wouts, 1991). However our knowledge of the tropical forms is almost non-existent as most work has been based on temperate species. Soil-baiting could provide useful new isolates with practical prospects. In addition, there are many nematophilic nematodes of potential interest for biocontrol of plant feeding nematode pests.

130 The discovery and development of new agents for biological control will always rely on accurate taxonomy. There are many cases where failure to identify the host or the parasite precisely has led to the failure of programmes. A symbiosis between biosystematists and biocontrol specialists remains the key to the development and implementation of successful biocontrol programmes (Knutson, 1981). In the future there will be a growing need to separate strains and subspecific populations with particular virulence characteristics or host preferences, not only in microorganisms but in invertebrates too.

BIOPRODUCTS

131 The exploitation of natural products from invertebrates and microorganisms by man includes a wide range of traditional materials such as honey and wax from bees, shellac from scale insects, silk from moths, edible mushrooms and other fungi, and fermentation products from yeasts. However the rapid growth of biotechnology and genetic engineering promises a new industrial revolution in which the use of microorganisms may provide a huge range of new products. Currently human exploitation of microorganisms is worth tens of billions of US dollars annually. The current top selling 25 pharmaceuticals include 5 of fungal origin; these five earn US \$ 3.5 billion world-wide in 1991 (Phillips & Drew, *vide* N. Porter, pers. comm.).

132 Microorganisms are involved in the manufacture of bread, cheeses, yoghurt, fermented foodstuffs (especially in Asia), alcoholic beverages, food colourings, flavourings and preservatives; acids (e.g. acetic, citric, glutamic and oxalic acids); fuels (acetone, butanol, ethanol, biogas); enzymes, vitamins and many other products. A meat substitute protein, Quorn, can be produced from a strain of the bread mould, *Fusarium graminearum*. Green manure can be produced by growing legumes, sometimes also yielding bean crops, which are artificially inoculated with efficient nitrogen-fixing strains of *Rhizobium* and are ploughed in after harvest.

133 The little-known tropical microbiota are a potentially rich source of industrially important enzymes, pharmaceuticals and agrochemicals and most of the world's major pharmaceutical and agrochemical concerns have active natural product screening programmes. Although over 10,000 antibiotics are now known from microorganisms (mostly from actinomycete bacteria and certain filamentous fungi) (Nisbet & Fox, 1991), this is very much the tip of the iceberg -- an immense potential exists (Bull *et al.*, 1992). Genes specifying useful enzymes or other proteins can be engineered into other microorganisms and cultured on an industrial scale. For example the production of the insecticidal crystal protein from *Bacillus*

thuringiensis and the clotting factor 8 from humans have been separately engineered by transferring the requisite genes to the bacterium, *Escherichia coli*, and crop plants can have desirable genes inserted into them using microbial gene vectors such as the bacterium *Agrobacterium tumefaciens*.

134 The potentially available pool of naturally-occurring fungal pathogens of insects and plants may approach a level of one for one. Rust fungi are commonly restricted to a single plant species or genus and similar diversity may exist among some insect-parasitic fungal groups (Waage, 1991b). Formulation of fungal and viral strains as biopesticides does not require complex technology and is ideally suited to the labour-intensive agricultural economies of the third world (Prior, 1989). Indeed, local farmers in Brazil themselves prepare suspensions of macerated diseased caterpillars to spray on their crops (Waage, 1991b).

135 Industrial screening of microorganisms for useful enzymes and secondary metabolites have produced commercially important products such as the herbicide bialaphos and the potent anthelmintic compound ivermectin. Ivermectin, originally developed for veterinary use, is now being used in the campaign against human onchocerciasis (tropical river blindness), which affects 20-40 million people. In addition to antibiotic and toxigenic activity there are over 60 other types of pharmacological activity known from microorganisms (Nisbet & Fox, 1991).

136 The fact that less than 5% of the probable number of species of microorganisms existing are represented in the world's culture collections (Nisbet & Fox, 1991) is a serious constraint on their exploitation and equally on the completion of taxonomic research needed to classify them and reveal their evolutionary relationships. At present most species cannot be grown in culture and there is a need to develop new isolation and enrichment cultivation methods in order to obtain novel organisms (Bull, 1991). DaSilva *et al.* (1991) have pointed out that specific microbial gene sequences may be recognized in situ in environmental samples without laboratory culture. This approach, which they call microbial molecular ecology, will permit access to the gene pools of phenotypically unrecognized and undescribed microorganisms.

137 One result of the United Nations Conference on Environment and Development (UNCED) was a heightened awareness of countries with respect to their property rights over organisms from within their boundaries which were exploited in other countries. In view of the desire of many companies to continue screening programmes, developing countries could increasingly play a role in the isolation, sorting, and selling-on of microbial strains under contract. Merck are currently paying INBio in Costa Rica for plant extracts for screening and have outline plans to extend that programme to cover microorganisms in 1994. In the development of such activities, assistance with health and safety, patent and property rights aspects will often be essential (Farrington & Greeley, 1989).

QUARANTINE

138 The accidental introduction of pathogens and pests into areas of the world where they did not previously occur is a major cause of habitat degradation and reduction of biodiversity, and results in major losses to agriculture and forestry systems. Such introduced organisms spread unchecked in the absence of their natural enemies and are able to exploit hosts which have never been exposed to them and have little or no genetic resistance. The maintenance of effective quarantine at national boundaries is therefore of major importance.

139 Movements of infested plant material are a major source of exotic pests and pathogens. Chestnut blight (*Cryphonectria parasitica*), an Old World plant

pathogen, has caused stupendous losses since its introduction to North America around 1900. By 1960 the American chestnut, which previously made up 25% of the forest in the Appalachians, was almost eliminated throughout its native range (Ledig, 1992). The effect on other species dependent on this keystone resource can only be surmised. Several species of *Phytophthora* have been translocated into Australia and the USA, causing serious decline in native stands of *Banksia* and jarrah (*Eucalyptus marginata*) in Western Australia (para 64) and of Port Orford Cedar (*Chamaecyparis lawsoniana*) in the western US (where they are spread by transport of infected soil on off-road logging vehicles) (Ledig, 1992). The presence of pests on plant material or foodstuffs being exported can also have severe consequences on the trade and foreign exchange of developing countries. This also applies to ornamentals, the pathogens of which are much less well-known than those of well-established crops.

140 Many species of plant-sucking bugs are easily transported on plant material and scales, mealybugs, whiteflies, psyllids and aphids are a priority group for taxonomic research and quarantine surveillance. In recent years at least 10 species of this group have become established in Africa (2 black citrus aphids, cottony cushion scale, spiny blackfly, Russian wheat aphid, cassava mealybug, Russian wheat aphid (Bagine *et al.*, 1993) and 3 species of conifer aphids). At present a further pest, the leucaena psyllid, *Heteropsylla cubana*, has spread westwards from Central America and entered Africa in early 1993 (D. Hollis, pers. comm.). It causes serious losses to *Leucaena leucocephala*, a tropical multipurpose tree species (Muddiman *et al.*, 1992).

141 Many species of plant pathogenic nematodes have become serious quarantine pests. Of these the most important are the cyst and cystoid nematodes (Siddiqi, 1986). Two species of potato cyst nematodes occur in Europe, of which only one has been recorded from the US. Strict quarantine is applied to prevent the spread of the first species and the entry of the second species into the US. In India a single cyst nematode species, *Heterodera avenae*, is estimated to cause damage valued at US \$ 5 million in Rajasthan alone. This species and several other species of *Heterodera* constitute a quarantine threat to the ASEAN countries (Siddiqi, 1986).

142 The translocation of domestic animals carries the risk of accidental introduction of parasitic species. Helminth parasites of strains resistant to antihelmintics may thereby be spread to new areas. A particularly serious recent case was the introduction of the New World screwworm to Libya on infested livestock (Vargas & Hall, 1989). After the initial confirmation of the identity of the pest by IIE and NHM staff, a major sterile-male release eradication programme was instituted by the UN at a cost of several million US dollars.

143 Speed of response is essential in addressing pest introductions. Because the screwworm was detected and recognised early the infestation remained localised and has now been eradicated. If it had remained undetected for much longer it is likely that the insect would have spread into subsaharan Africa where the damage to wildlife, livestock and human health would have been incalculable and eradication virtually impossible.

144 For effective quarantine interception the responsible personnel need to know what pests and diseases are already present in their country and which species not yet present are likely to pose the most serious threats. Such information is not readily available for many African countries. However the *Distribution Maps of Plant Diseases* and *Distribution Maps of Pests*, published by CABI, and the *African distribution maps of major crop pests and diseases*, prepared by CABI for the Inter-African Phytosanitary Council (IAPSC) offer some pointers in this area. CABI has also participated in preparing datasheets on exotic pests and diseases for the European Plant Protection Organization (EPPO; Smith *et al.*, 1992).

145 Training in the recognition of pests, including their early stages, and as far as possible, the recognition of plant pathogenic nematodes and microbes is an urgent necessity. To this end suitable training materials tailored to the needs of quarantine inspection personnel need to be prepared (Bagine *et al.*, 1993; Siddiqi, 1986).

146 An unsatisfactory taxonomic base makes the assessment of risks of many quarantine fungi in particular uncertain. Not only may "special forms" not have been tested against the full range of crops in a region, their effects on native plants are unlikely to have been tested experimentally.

Biosystematic Resources in Developing Countries

BACKGROUND

147 In order to assess the ability of developing countries to inventory and monitor their own biodiversity, it is first necessary to identify the resources that are already present. In this chapter, estimates (or indications) of the various types of resources necessary to support in-country biosystematic work in relation to microorganisms and invertebrates are first compiled. These comprise reference collections, information, and human resources.

REFERENCE COLLECTIONS

148 The mycological resources of tropical countries have been assessed by Hawksworth (1993a). Of the 158 herbarium collections identified which include dried reference specimens of fungi, 82 (51%) are located in just six countries (Australia, Brazil, India, Mexico, China and South Africa). Few such collections exist in any other tropical countries and of these most are small, unrepresentative and poorly staffed. Many comprise a limited range of either pathogens of crops, lichens, or perennial macromycetes so are of limited value as back-ups for major biodiversity surveys. A listing of the dried fungal reference collections known to exist within tropical countries is shown in **Annex 1**, based on the compilations of Hawksworth (1993a) but supplemented by other sources; most notable amongst the latter is recently released directory of African mycologists (Buyck & Hennebert, 1992). Of 142 countries listed in **Annex 1**, 91 (64%) have no known fungal collections.

149 In the case of bacteria, many groups of fungi (including yeasts) and certain microalgae and protozoa, dried reference collections do not preserve material in a state suitable for comparison during identification or as vouchers. Only living cultures are acceptable as nomenclatural types in bacteria. In the case of the fungi, living genetic resource collections (culture collections) are maintained at many fewer sites than are dried specimens (**Annex 2**). Only 29% of the tropical countries listed in **Annex 2** have any such culture collections. Of 107 tropical collections listed in the *World Directory* (Takishima *et al.*, 1989), 52 (49%) are located in just two countries, Australia and India. UNESCO has recognized the importance of such collections since the 1940's and has fostered the development of Microbial Resource Centres (MIRCEN's) in nine developing countries (DaSilva, 1991). Such collections, as well as their taxonomic role, have a unique value in making available indigenous microbiological genetic resources for research, screening and exploitation. The development of such facilities gives developing countries a tangible stake in the future of their biological resources and an economic justification for preserving biodiversity (*para 137*). Guidelines for the establishment and operation of such collections have been issued by the World Federation for Culture Collections (1990).

150 The major insect and spider collections of the world have been listed by Arnett & Samuelson (1986) and Ritchie (1987) reviewed those of Africa. The known entomological collections of the tropics are shown in **Annex 3**. This listing indicates that 44 (31%) tropical countries have no known insect collection. Of these, less than 37 institutions are known to have collections in excess of 100,000 specimens. The last attempt to catalogue the entomological collection resources of

the tropical world (UNESCO, 1962) listed only 13 institutions or individuals in Africa with significant insect collections. In 30 years this has now grown to 75 collections, and while more undoubtedly exist, their scope is often limited to agricultural pests or lepidoptera and standards of curation are frequently unsatisfactory.

151 Even fewer tropical countries are known to have institutions housing reference collections of plant nematodes and animal helminths (**Annex 4**). Of these, nine have reference collections of animal helminths and eight have nematode collections.

152 The data in **Annexes 1-4** are summarized in **Annex 5**. This shows the numbers of reference collections of microorganisms, insects and nematodes and helminths. Insect collections far outnumber others, largely because of the ease with which these organisms can be collected and preserved. Collections of microorganisms are especially scarce in Africa and poorly represented in Central America and the Caribbean.

153 It is also pertinent to stress here that, almost without exception, much of the critical reference material (including types; see *para 188*) relating to a particular tropical country is not preserved there but in those of former colonial powers in Europe (and to a lesser extent North America). Although the practices of both expatriate collectors and taxonomists are changing, with named duplicates being deposited in the country of origin, that is not universally so and does not affect the situation for historically important earlier collections. This problem is not unique to developing countries; indeed Australia suggested that material from its country held in The Natural History Museum should be repatriated if it could not continue to be curated satisfactorily there (W D L Ride, *in* House of Lords Select Committee, 1992). The repatriation of types would cause major problems for systematists in both developed and developing countries as most species are not confined to a single country. Holloway (1983) estimated that if this occurred an oriental entomologist might have to visit all capital cities from Delhi and Peking to Suva and Canberra. Developed country institutions are generally willing to loan material to *bona fide* researchers elsewhere, but even where the museum with the required specimens has been located, the costs of shipping the loan back may present major problems.

154 Reference collections are not only crucially important for checking identifications and providing key raw material for biosystematic research. They are the basic tool for communicating information about biodiversity, and the key to the interpretation of all organismic biology research. Further, the collection details accompanying specimens are a database of information on past and present geographical and altitudinal ranges, host and substrate specificities, and seasonality (Hawksworth & Mound, 1991). Collections are consequently of importance also to conservationists and those involved in crop protection risk assessment.

INFORMATION RESOURCES

155 Scientists and conservationists concerned with biodiversity assessments and monitoring require information about the organisms known from their country. There is a strong tradition of checklists of species, bibliographies, and Floras and Faunas in biology, especially for flowering plants, birds, fish, mammals and lepidopterans. However, for most groups of invertebrates and microorganisms these critical basal national and regional reference works do not exist. Those wishing to identify material and who are working in the tropics consequently lack a point of entry the accumulated knowledge of the biotas of their own countries.

156 Compilations are especially critical as much of the published information is in journals and books published in Europe (and to a lesser extent North America)

through the last 150-200 years. I.e. during periods when no major libraries existed in many countries. Further, for most regions there is no single source work to the key literature on the identification of all groups, equivalent to that of Sims *et al.* (1988) for north-west Europe.

157 For insects, there are almost no recent works describing whole country Faunas, with the notable exception of the *Insects of Southern Africa* (Scholtz & Holm, 1985), *Insects of Australia* (CSIRO, 1970) and the *Insects of Nigeria* (Medler, 1980). Regional or country checklists seldom cover more than one family or, at most, one superfamily. For most tropical countries fungal checklists are non-existent, even for plant pathogens and other economically important groups, and descriptive accounts and monographs are even rarer (**Annex 7**). On-going projects such as *Flora Neotropica* (New York Botanical Garden, 1968 on) and *Flore Illustrée des Champignons d'Afrique Centrale* (Jardin Botanique National de Belgique, Brussels, 1935 on) cover fungi, but will not cover even the known species in their regions at the current rates of progress for several centuries to come (Hawksworth, 1993a).

158 Even where a researcher identifies the title of a paper or book needed for his systematic work, such works are widely dispersed and often difficult to obtain even as photocopies. They can often only be located overseas and obtained with foreign currency. In the absence of compilations and other synoptic studies the problem is exacerbated as both taxonomists and those wishing to identify specimens are forced to search for individual species descriptions, often in obscure journals. The scale of the problem can be indicated by experience with the *Index of Fungi*, prepared at IMI, and which catalogues the world's fungi as they are described. This *Index* cited names published in 851 titles (of which 674 were journals) in the period 1981-90 (Hawksworth, 1993a). Runs of this source *Index*, and the equivalents for zoological (*Zoological Record*) and bacterial (*International Journal of Systematic Bacteriology*) groups are rarely present in developing country libraries. Even broader abstracting journals are often incomplete, and those that do exist are not indexed down to the level taxonomists require.

HUMAN RESOURCES

159 The numbers of personnel involved in taxonomic work with invertebrates and microorganisms based in the tropics are insignificant in relation to the magnitude of the task before them. Gaston & May (1992) produced evidence suggesting about 80% of the world's insect taxonomists are based in North America and Europe. Ritchie (1987) estimated that in South Africa there were perhaps 30 insect taxonomists, with less than half that number employed in the rest of the continent. Hawksworth (1993a) estimated from experience at IMI that a team of 25 specialists would be needed to provide adequate national expertise on all major groups of fungi; no single centre even in Europe or North America has that number of full-time biosystematic mycologists. He listed nine countries (Australia, Brazil, Egypt, India, Mexico, South Africa, China and Taiwan) where such a critical mass might exist. Further indicators of the resource base for mycological investigations within tropical countries are included in **Annex 7**. This **Annex** offers an indirect estimate of the professional staff who are involved in mycology in tropical countries, through the membership of national and international societies. No comparable tabulation exists for other groups of organisms. Once again there is particularly low representation in Africa (relative to its population) while Asia and Australasia/Pacific appear relatively well represented.

160 Even where specialists do exist in a particular country or region, they can be scattered through different institutions and unaware of each other's existence. Regularly revised and freely available directories are therefore essential. *Index*

Herbariorum (Holmgren *et al.*, 1990) list the specialisms of taxonomists in institutions with botanical (including fungal) dried reference collections, and more recently a *Directory of African Mycology* was compiled (Buyck & Hennebert, 1992). In the process of compiling that *Directory*, questionnaires were sent to 607 addresses that it was thought might well have mycologists and responses were received from 224 (Table 1); most countries yielded 0-5 replies -- a particularly worrying situation as this questionnaire was directed at all who work with fungi (including pathologists and medical mycologists) and was not restricted to taxonomists.

161 Some of the institutions listed in Annexes 1-4 lack any permanent taxonomic specialists in microorganism or invertebrate groups. A common pattern is for a national collection to have a single mycologist (or lichenologist) and entomologist. In practice, much of the time of such key staff tends to be directed into curatorial duties rather than taxonomic research or identification. In Australia, Pascoe (1990) noted that the ratio of fungal species to fungal taxonomists in the country (less than 15) was 16,667:1, as against 18:1 for fern species. An even more striking pattern would be expected to emerge from a comparison of, for example, relative numbers of ornithologists and entomologists.

162 Even where permanent positions exist, or where funding for project staff is obtained for biodiversity studies, in the case of microorganisms and invertebrates suitably trained scientists are rarely to be found. In tropical universities training in taxonomic theory and practice and in systematic aspects of entomology, nematology or mycology is almost non-existent. Kumar (1987), discussing the training of entomologists in Africa, concluded that university training in entomology was extremely poor and proposed that international organizations should establish Masters Degree programmes in association with African universities on the model of the International Centre for Insect Physiology and Ecology (ICIPE) in Nairobi which runs an African Regional Postgraduate Programme in Insect Science (ARPPIS). That also offers a PhD programme which includes course work in systematic entomology (Smalley, 1987).

163 In-country short courses or practical training attachments in tropical institutions are the exception rather than the norm. However, the CABI institutes have collaborated in providing taxonomic training courses in mycology and entomology in Argentina, Brazil, Chile, China, Egypt, India, Kenya and Malaysia during the last ten years. Future courses are planned for Thailand, Sri Lanka and Ukraine. The National Museums of Kenya, Nairobi has also offered basic taxonomic training attachments to staff from other countries in Eastern and Southern Africa.

164 At the level of technical assistance a system of "parataxonomists" has been developed in Costa Rica with school leavers being trained to collect useful samples of insects for the National Biodiversity Institute (INBio). This is intended to be part of a system of public education about the value of biodiversity particularly aimed at school children. It also constitutes a benefit (employment) from biodiversity for a part of the community which might normally not gain from biodiversity studies.

GENERAL INFRASTRUCTURE PROBLEMS

165 Many tropical reference collections face enormous practical difficulties. High ambient humidity combined with high daytime temperatures encourages growth of spoilage fungi on dried specimens. When air-conditioning, dehumidifying and refrigeration equipment are installed they are subject to frequent interruptions in the electricity supply and fluctuating voltages which reduce the useful life of appliances. Spare parts and maintenance may be expensive and down-time indefinite. Library

Table 1. Alphabetical list of the numbers of questionnaires sent out and answers received in the course of preparing the *Director of African Mycology* (Buyck & Hennebert, 1992).

	Addressees	Answers
Algeria	2	2
Angola	2	0
Benin	15	2
Burkina-Faso	6	4
Botswana	1	1
Burundi	4	3
Cameroon	8	3
Congo	6	1
Egypt	72	4
Equatorial Guinea	0	0
Ethiopia	15	6
Gabon	6	2
Gambia	1	0
Ghana	9	3
Guinea	1	1
Guinea-Bissau	1	0
Guinea Conakry	2	1
Ivory Coast	15	9
Kenya	22	13
Lesotho	0	0
Liberia	1	0
Madagascar	5	1
Malawi	5	1
Mali	2	1
Marocco	7	6
Mauritius	8	3
Mozambique	4	0
Namibia	0	0
Niger	7	1
Nigeria	116	35
Rep. South Africa	160	75
Réunion	1	1
Rwanda	3	6
Senegal	14	3
Sierra Leone	5	3
Somalia	0	0
Sudan	12	3
Swaziland	2	0
Tanzania	17	10
Tchad	2	0
Togo	2	1
Tunesia	6	3
Uganda	5	2
Zaïre	5	3
Zambia	12	3
Zimbabwe	18	8

materials as well as specimens and their paper labels are subject to attack by termites, book lice, silver fish and beetles.

166 Suitable chemicals to protect specimens are expensive, short-lived in their effectiveness and may entail health risks to staff. Secure storage boxes and collection drawers are generally imported and may be locally unavailable. For culture collections, continuous supplies of electricity for deep freezes are prerequisite, and to preserve some groups regular liquid nitrogen supplies are required. While it is theoretically feasible to design and install a liquid nitrogen generating plant alongside the refrigeration flasks, as has been done in Institute of Microbiology in Beijing (D L Hawksworth, pers. comm.) this is not a realistic option for most developing countries. Freeze drying equipment has much to commend it for culture preservation in certain fungi and bacteria, but spares are often difficult to obtain; broken freeze dryers are a common feature of tropical microbiology institutions. Many older facilities are highly vulnerable to fire and lack basic equipment for detecting, retarding or fighting fires.

DEVELOPING COUNTRY NEEDS FOR TRAINING AND INFRASTRUCTURAL SUPPORT

167 There is an obvious need for support for training at all levels of personnel from tropical developing countries. The aim of such training is technology transfer to build an indigenous capability in those countries and increasingly to train trainers who will themselves train others (Swaminathan, 1990).

168 In the field of short courses for technical and professional staff, CABI has had a major impact over recent years with more than 1000 trainees participating in its UK-based and other courses (*para 163*). The numbers and geographical origin of trainees on CABI courses which are entirely or partly taxonomic are given for the years 1985-92 in **Annex 8**. These figures represent a small proportion of the demand for biosystematic training as many applicants are unable to secure funding, and courses are not infrequently oversubscribed even though advertising is minimal. The limiting factor is financial support to enable trainees to attend such courses (Ritchie, 1992).

169 While short-courses are valuable for teaching techniques, and as "refreshers" for established staff, they are not able to provide the in-depth level of training necessary to provide an on-going cadre of specialists. The longer term aim must be to have high quality in-country university courses with taxonomic contents relevant to invertebrates and microorganisms in tropical countries. However, in the immediate future it is important to identify young science graduates of high quality who can be registered for split-PhD postgraduate training in European or North American biosystematic institutions but registered in their own countries and with co-supervisory arrangements. After completion of a suitable PhD research project these researchers need to be placed at key regional centres of excellence in the tropics and provided with adequate resources to continue to function as taxonomists. As PhD theses are necessarily narrow in scope, where possible post-doctoral placements or periods as visiting scientists in other institutions are of particular value.

170 Sands (1981) indicated that the development of a really efficient insect taxonomist might take ten years, and this is also true for mycologists at IMI (D L Hawksworth, pers. comm.). Institution-building is consequently necessarily long-term, requiring a high level of coordination and commitment on the part of all concerned -- the trainee, the host institute, the facilitating institute, and the donor. In time the products of such a system will be able to collaborate with their national universities to reproduce the same beneficial relationship between research

institutions and postgraduate training institutions. This is starting to occur in Trinidad & Tobago where at the Central Experimental Station at Centeno five staff have attended IMI and IIP courses since 1979, and another an MSc (IMI/ University of Reading) who is registered at the University of the West Indies for a PhD. As the level of local expertise has increased, the numbers of pathogens submitted to IMI for identification has decreased markedly.

171 If a long-term institutional-building system is to contribute to the elucidation and sustainable use of tropical biodiversity then national and regional institutions involved in biosystematics also need to provide a career structure which gives reasonable prospect of reward and promotion in taxonomic research (Sands, 1981; Swaminathan, 1990).

172 The need to concentrate resources in a few regional centres was recognized in the 1970s by the African Association of Insect Scientists (Kumar, 1981). At about the same time, Subramanian (1982) argued for the establishment of an Institute of Tropical Mycology. Haskell & Morgan (1988) identified networking as the best way to move forward with limited resources. A formal global Network of Biosystematic Centres was advocated by an international workshop on the significance of biodiversity in microorganisms and invertebrates (Hawksworth, 1991b). It was recognised that the development of such a system would involve both the strengthening of existing centres and the development of new ones, through training, infrastructure building, and information structure. This concept, now provisionally termed BIONET, has been developed in outline (Jones, 1992; **Annex 9**). This envisages a system of regional LOOPS linked through co-ordinating centres to a consortium (BIOCON) of the world's major institutions concerned with the systematics of microorganisms and invertebrates, serviced by a central secretariat. The BIOCON partners would play key roles in institution-building and training, and be available to assist with critical identifications where necessary. In view of the large numbers of taxa involved, no single country will ever be self-sufficient in biosystematics.

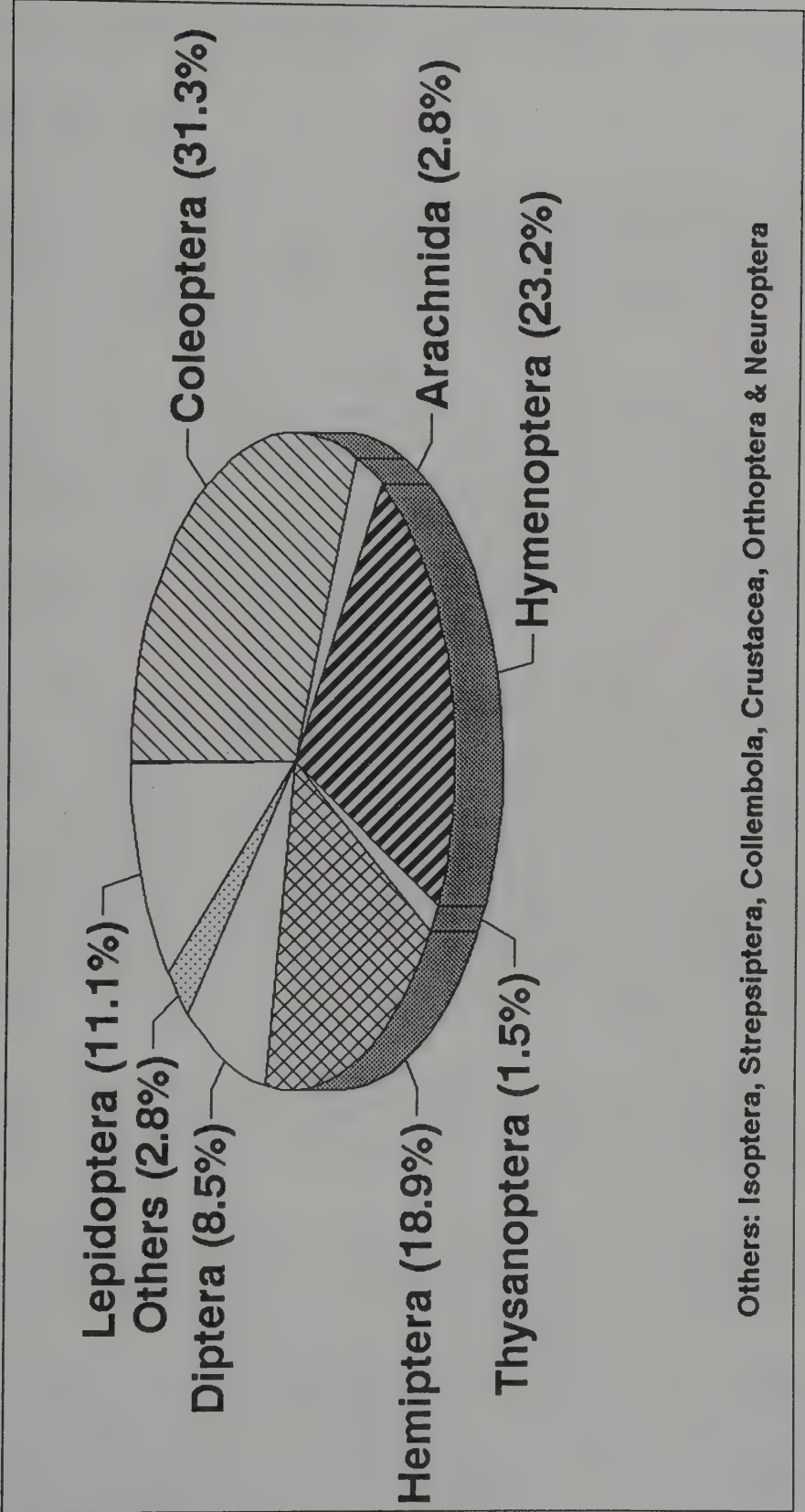
173 The formation of a Caribbean LOOP is being planned, following recommendations of an International Workshop on Diagnostic Services for Agriculture and the Environment held in Port of Spain in May 1992 (Ainsworth & Hawksworth, 1992). The concept was endorsed by the Ministers of Agriculture of 12 of the CARICOM countries in Barbados in June 1992, and a follow-up planning meeting was held in November 1992. The possibilities of developing further LOOPS in India, Indonesia, Malaysia and southern and East Africa are being explored further in 1993 with the support of the CABI Partnership Facility (to which ODA contributes). A key meeting of representatives of BIOCON members and LOOP nodes is scheduled for 11-12 June 1993 at The Natural History Museum, with partial funding from ODA.

174 While the LOOPS become established, developing countries will have a continuing requirement for identification of even the commoner microorganisms and invertebrates in their countries. This service was supplied free of charge to the world by the three CABI biosystematic institutes (*paras 14-17*) until 1979 when charging for submissions from non-member countries was introduced. Since the early 1980s, however, these institutes have of necessity implemented increasingly rigorous acceptance criteria; at IMI, the numbers of identifications undertake each year have fallen from around 12,000 to 4,500 each year over this period in accordance with the policies of CAB International. The spectrum of different arthropod groups named by IIE in 1991 is indicated in **Fig. 3**. The wide range of countries requiring such services is illustrated by an analysis of material received by IIP in 1983-91 (**Annex 6**), and the need voiced in studies commissioned under CABI's Partnership Facility in 15 countries in 1991-92: Bangladesh, Belize,

Guyana, India, Indonesia, Jamaica, Kenya, Malawi, Myanmar, Nepal, Nigeria, Sri Lanka, Thailand, Vietnam, and Zambia.

175 There are also urgent needs to enhance the reference collections and literature resources in key national biosystematic centres. The value of such collections can be increased by either named material being returned (the IIE practice), or senders being instructed to split specimens which they can label after an identification report is received (the IMI practice). In addition, several of the major world mycological herbaria have duplicate material available for regular exchange for other named collections. The countries with which IMI currently operates exchange programmes include Brazil, China and the Ukraine. The Institute's latest *Duplicate Collection Catalogue* lists 780 different species.

176 In view of the scale of the problem, and the absence of regional and national synthetic works, the building of adequate literature collections to a satisfactory level poses especial problems. However, new delivery options are becoming available through the combination of OCR inputting and CD-ROM technologies, and also expert systems and identification programmes (*paras 192, 194*). CABI's Information Services have found CD-ROM's especially suitable for use in developing countries. For example, CABI's TREE-CD, covering world forestry literature published since 1939 and first issued in 1991 is currently in use in 20 developing countries (mainly through sponsorship arrangements).



Insect Names in IIE Reports 1991: Proportion from each Order

Biosystematic Resources in Developed Countries

BACKGROUND

177 There is widespread concern at this time as to the state of biosystematic resources in developed countries, as well as developing ones. This is indicated by emotive headlines such as "The Disappearance" (Isley, 1972), "Entomologists wane as insects wax" (Holden, 1989), "Will taxonomy go the way of the dinosaurs?" (Hamer *et al.*, 1990), and "What must be done to save systematics?" (Bisby & Hawksworth, 1991).

178 The problem is a long-standing one. As far back as 1944, the British Mycological Society issued a pamphlet *The Need for Encouraging Systematic Mycology in England and Wales*. In the case of entomology, attention was drawn to the resource problem in the USA by the Entomological Society of America in 1974 (Fischer *et al.*, 1974). Both the European Science Foundation (Heywood & Clark, 1982) and the National Science Foundation (Edwards *et al.*, 1986) have commissioned assessments of the situation. The NSF report is of especial interest in indicating that of all taxonomists in North America, while 32% are entomologists, a mere 2% are microbiologists (Gaston & May, 1992).

179 A report carried out for EEC Directorate General XII in 1985 (Jago, unpublished) sought to determine the extent of entomological taxonomic work in EEC member country institutions relevant to the improvement of agriculture in developing countries. Of the 21 organizations responding to a questionnaire enquiring into their links with tropical developing countries, eight had no such links. The remaining countries with developing country links included a group of 11 small institutions with six or fewer taxonomic staff, most of whom were only part-time taxonomists. Only two other organizations with such links were identified -- the NHM and IIE. Between them these two organizations then deployed 63 full-time entomological research staff and provided a comprehensive identification service for tropical crop pests. Although this total has now been reduced by about one third, it still represents the largest concentration of systematic entomologists in Europe.

180 The International Union of Biological Sciences (IUBS) has passed resolutions expressing concern at the lack of support for taxonomy at every General Assembly it has held since 1973, the most recent being that in Amsterdam in 1991 (Younès, 1992).

181 In the USA, the shortage of entomological taxonomists has been referred to as an "expertise crises" (Wheeler, 1990), and a major initiative SYSTEMATICS AGENDA 2000 is currently underway to integrate the various disciplines affiliated to the study of biodiversity and systematics. Its proposals have yet to be published.

182 In this chapter, the main focus of attention will be the UK, references being made to other institutions where appropriate. The overall situation in developed countries is similar, with the notable exception of Australia where special funding was secured to establish a Bureau of Fauna and Flora (later the Australian Biological Resources Survey, linked to ERIN) able to commission monographic studies of the Australian biota.

183 The taxonomic resource base of the UK has been investigated by several agencies in the last 15 years. That of the Advisory Board for the Research Councils (1979) resulted from widespread concern but led to little action. However, more recently The House of Lords Select Committee on Science and Technology (1992) conducted an enquiry "to consider systematic biology research in the United Kingdom" in the light of a growing perception that systematics is declining in the UK, and in particular the widespread unease generated by the staff cuts at the Natural History Museum.

184 The Linnean Society of London (Claridge & Ingrouille, 1992) has examined teaching and research in Higher Education Institutions by means of a questionnaire. That revealed that only 8% of life sciences departments taught foundation courses in systematics and reported a decline in the relative numbers of PhD theses in taxonomy as compared to biochemistry since the 1950s. They also noted the ageing population of teaching staff with taxonomic research interests. A 1992 survey of mycologists of all types in UK universities and other HIE's revealed only 41 full-time positions, 61% of which were over 46 years old, and only six were under 35 years (A.J. Trinci, pers. comm.); only four of those 41 posts undertake biosystematic work on fungi. The profiles parallel that of endangered vertebrates considered as approaching extinction and as candidates for captive breeding (Gaston & May, 1992).

185 The Natural Environment Research Council (1992) sought to identify and examine new scientific opportunities in the field of taxonomy and related disciplines. The NERC report notes the House of Lords report's suggestion that the Advisory Board for the Research Councils (ABRC) should direct additional funds to taxonomic research and makes broad suggestions as to how additional funding might be spent.

186 In June 1992, during UNCED (*para 22*), the UK announced the establishment of the Darwin Initiative for the Survival of Species, aimed at mobilizing the UK biosystematic resources in support of biodiversity in developing countries. The programme is being administered by the Department of the Environment, and submissions as to how its funds might be utilized were invited. CABI's submission is included at **Annex 10**. The Advisory Committee for the Initiative is to hold its first meeting in April 1993.

REFERENCE COLLECTIONS

187 The House of Lords Select Committee Report (1992) provides an estimate of the collection resources of the 17 major UK museums in terms of the numbers of specimens held. The CABI institutes rank within this grouping in terms of the size of their collections, although IIE donates material it accrues to the Natural History Museum. The NHM has by far the largest collections in the UK and for historical reasons these are of much greater relevance to tropical biodiversity than those of most other UK museums. In addition it is also pertinent to draw attention to two other compilations: Hancock & Morgan (1980) distinguish British and Foreign holdings on a higher taxon basis, and Williams (1987) provides fuller information on staffing and curation levels. A conference to consider whether the UK should develop a national plan for systematic collections was held in 1982 (Morgan, 1986).

188 The UK collections of insects and fungi are unparalleled elsewhere in the world in importance (i.e. in the numbers of type collections, the specimens to which scientific names are permanently linked) and also size. The Natural History Museum alone has around 30 million insect specimens; and the fungi dispersed between the Royal Botanic Gardens Kew, IMI, and Museum (lichenized species) together amount to around 2.5 million specimens. This triumvirate is approached

only by the US National Fungus Collection (USDA, Beltsville) with around 1 million specimens. The living collection of fungal strains at IMI incorporates the UK National Collection of Fungus Cultures and is the third largest service collection in the world; the two larger being the American Type Culture Collection (ATCC) and the Centraalbureau voor Schimmelcultures (CBS) in The Netherlands. The 10 UK national microbial culture collections, data from which is incorporated through IMI into the Microbial Information Network Europe (MINE), are exceeding in Europe on the basis of the number of strains held only by The Netherlands (Aguilar, 1990).

189 With the exception of the culture collections contributing data to MINE, the enormous amounts of information these collections represent can only be accessed by personal visits. The CABI Institutes have, however, endeavoured to contain the escalating problem by computerizing all material received since 1989. This initiative was commended by the House of Lords Select Committee (1992) and is directly relevant to the needs of developing countries as it enables outputs on a country basis to be produced on demand.

INFORMATION RESOURCES

190 Although there are no in-depth analyses, the collections of biosystematic literature available in the UK as a whole almost certainly place the UK in a preeminent world position in this regard. This circumstance arises from the securing of the library of Linnaeus (in the rooms of the Linnean Society of London), that of Sir Joseph Banks (in the British Library, Bloomsbury and NHM), and the policies of successive directors of the Royal Botanic Gardens Kew and NHM. Further, because of the UK's pivotal role in biological nomenclature, resulting from the publication of the *Index Kewensis*, *Index of Fungi*, and *Zoological Record*, and the location of the International Commission on Zoological Nomenclature's office in the NHM, copies of original descriptions of new taxa are secured.

191 The UK's crucial nomenclatural indexing roles are likely to be enhanced if proposals to require the formal registration of publications including new names in algae, fungi, and other "botanical" groups) are accepted at the International Botanical Congress in Yokohama in August 1993. IMI has also contributed since 1988 in the compilation, circulation, and editing of lists of generic names of fungal groups for which specially protected nomenclatural status is to be sought at that same Congress. The Institute also prepares the twice-yearly *Bibliography of Systematic Mycology* (from 1946) and, at intervals of about 10 years, the *Dictionary of the Fungi* (from 1943). IIE has recently been involved in the preparation of a list of preferred names of arthropods of economic importance (Wood, 1989), and a 60,000 name computerized arthropod name index, ANI (Scott, 1991). Parallel initiatives on nematode (NEMA) and plant bacterial names are in progress.

192 It is also pertinent to draw attention to the CAB ABSTRACTS database, containing abstracts of the world literature on agriculture and related fields. All data compiled since 1973 is available on CD-ROM as well as by on-line searching. Specialist CD-ROM's are also issued (see e.g. *para 176*). IMI also prepares a series of *Mycological Papers* including taxonomic revisions, and has issued 1080 *Descriptions of Pathogenic Fungi and Bacteria*. IIE prepares the prestigious *Bulletin of Entomological Research*. CABI has been actively extending its book publishing programme since 1988 and currently issues about 50 titles per year -- including identification manuals from its Institutes.

193 Professor P H A Sneath pioneered numerical approaches to bacterial identification and taxonomy at the University of Leicester from the 1960s and the UK has remained preeminent in this field also now pursued through groups at the University of Liverpool, University of Newcastle upon Tyne and the Public Health Laboratory Service at Colindale. With advances in computer technology, ever more sophisticated systems are becoming available. An automated system for identifying plant pathogenic bacteria using fatty acid profiles analysed by gas chromatography was developed at the MAFF Harpenden Laboratory in 1985 and is now available commercially.

194 More recently, IIE has developed an interactive computerized identification system, CABIKEY, for the identification of fruitflies. The system uses a "mouse" and coloured screens to guide users to a correct identification. A probabilistic computerized identification system to *Penicillium*, PENIMAT, was released on disc by IMI in 1992 (Bridge *et al.*, 1992).

195 A particularly ambitious expert system, which ultimately aims to cover all groups of organisms, the Expert Taxonomic Information (ETI) system, is currently under development at the University of Amsterdam. This has enormous potential for the delivery of systematic information in a user-friendly way and CABI is monitoring its progress with interest.

HUMAN RESOURCES

196 The House of Lords Select Committee Report (1992) found that the largest performer in the UK with regard to human resources devoted to biosystematics was, once again, The Natural History Museum (24.6% of total). CAB International, with 8.7%, devoted the third largest share of resources after the NHM and the Royal Botanic Gardens, Kew (13.8%).

197 Bearing in mind the ageing population of UK biosystematists (*para 184*) teaching and training in systematics is of especial concern. The House of Lords Report supported the Royal Society's belief that taxonomic training was best provided at postgraduate level. However, there are only two established MSc courses in taxonomy in the UK, Pure and Applied Plant and Fungal Taxonomy (University of Reading), and Applied Entomology (University of Wales Cardiff); a second MSc in plant taxonomy was launched by the University of Edinburgh in 1992. All three courses regularly have overseas students, and the Reading course has had 10-12 extra UNDP-funded students for one of the terms in the last three years. Some witnesses to the House of Lords Committee felt that a further MSc level course in taxonomy was needed and that it should involve collaboration with a major taxonomic institution. In line with this view, NERC invited applications for a Taxonomy Initiative to support three universities as centres of excellence in taxonomy by December 1992. Notwithstanding the results of that competition, Imperial College, London, and the Natural History Museum are considering develop closer links in teaching postgraduates. IMI has contributed to an MSc in Fungal Biotechnology at the University of Kent since 1990 (which has a significant taxonomic unit) and now that it is located close to Royal Holloway University of London further collaboration in teaching with that college is being scheduled for 1993/94.

198 It is also pertinent to emphasize that changing policies at the CABI Institutes and also at national museums and other institutions means that the biosystematics manpower present is not now necessarily able to identify the large numbers of specimens submitted from overseas as was the case up to the late 1970s (*para 174*).

GENERAL INFRASTRUCTURE PROBLEMS

199 The House of Lords Select Committee (1992) endorsed the view that there should be increased collaboration between the UK-based biosystematic institutions through the establishment of a forum. This would be a logical step, in sympathy with earlier suggestions (Morgan, 1986), and merits encouragement. In the USA an Entomology Collections Network (ECN) has already been formed by 19 institutions as a basis for collaboration on a wide range of issues (Kim, 1989). However, any formal collaboration between institutions with disparate obligations and funding arrangements is likely to require substantial additional financial support if this is to involve the development and implementation of a national strategy.

Priority Actions to Strengthen Biosystematics in Support of Biodiversity in Developing Countries

200 In view of the magnitude of the knowledge-gap on the biodiversity of microorganisms and invertebrates in comparison to that of macroorganisms (*paras 29-34*), the extremely limited resources available in developing countries (*paras 148-164*), and also the difficulties taxonomy is experiencing in many developed countries (*paras 177-186*) the prioritizing of actions merits particular care.

201 This chapter identifies ten Actions for priority support which can confidently be expected to have tangible results in the short- to medium-term (3-10 years) and which will enable the beneficiary countries to comply more fully with the Convention on Biological Diversity and to participate in the implementation of AGENDA 21 (*para 22*).

202 Many of the topics identified as being of high priority here have also been recognized as of critical importance in a variety of scientific contributions, recommendations from conferences and workshops, and special reports. In the development of detailed proposals for implementation, it would therefore be prudent to dovetail actions taken into other national, regional and international programmes wherever practicable. Examples of such initiatives are the national Biodiversity Action Plans being supported through the Global Environment Facility (GEF), DIVERSITAS (*para 21*), MICROBIAL DIVERSITY 21 (*para 21*), the Commonwealth Science Council's *Biological Diversity and Genetic Resources* (*para 25*), the Darwin Initiative (*para 186*), and the NERC Taxonomy Initiative (*para 185*).

203 Ten Actions required to strengthen and biosystematics in microbial and invertebrate groups in support of biodiversity in developing countries have been identified. These are listed below in order of priority.

ACTION 1: Strengthen and increase the effectiveness of biosystematic resources in developing countries through the development of networks with developed country institutions.

Benefit: To enable developing countries to become increasingly self-sufficient in their ability to provide timely diagnostic services for microorganisms and invertebrates of environmental and other importance to humans, and further to implement more fully their commitments under UNCED. This will also reduce dependence on developed-country institutions for routine identifications that they are increasingly unable to meet the demand.

Implementation: Organization of a system of national and regional networks (BIONET) linked through a local node into a consortium of developed-country biosystematic institutions (BIOCON) that would assist in training, resource building, and with identifications of critical material. The arrangements need to set in place through detailed surveys of existing resources and needs, and workshops to develop a programme for concerted action to create an

operational network. Commitment from the governments involved is needed to ensure continuance after an initial agency-funded phase.

Refs: *Paras* 169-175, Annex 9.

ACTION 2: Develop protocols for the standardized sampling of microorganisms and invertebrates for biodiversity assessments.

Benefit: Ability to generate comparable datasets for use in the assessments of the relative biodiversity of different sites as a tool in determining national and regional conservation priorities.

Implementation: Holding workshops of specialists on particular groups, with the brief to recommend a standardized system capable of use by non-specialists. The production of draft manuals for field-testing would then need to be commissioned, with a view to the publication and distribution of internationally acceptable procedures.

Notes: This activity needs to be pursued in conjunction with other groups who have recognized the need, including the Smithsonian Institution, IGBP Global Change and Terrestrial Ecosystems Change, and DIVERSITAS. Responsibility for particular groups could be distributed.

Refs: *Paras* 41-43, 47-49.

ACTION 3: Upgrade the basic biosystematic knowledge of microorganisms and invertebrates with keystone roles in ecosystem function, or aspects of pest control (including biocontrol), bioindication, waste utilization, food security and human health.

Benefit: Provision of the scientific basis necessary for species diagnosis, including the generation of information to be included in manuals for use in both biodiversity assessments and applied biology.

Implementation: Recognizing that taxonomic revisions of large groups are potentially open-ended, and that their quality is dependent on scarce taxonomic skills, a programme of 3-5 year grants open to competition to both universities and other institutions is commended. The grants would need to be sufficiently flexible to allow for post-doctoral scientists working in teams of 2-3 with technical support in order to make major progress in such a defined time-scale.

Notes: Organisms meriting priority attention include keystone groups [mycorrhizal fungi (ecto- and endo-), cyanobacteria, earthworms, termites, parasitic *Hymenoptera*, ant/seed/pest interactions, pollinators]; bioindicators [spiders, beetles, butterflies and moths, lichens on trees, leaf-inhabiting microfungi]; those important in ecosystem function and processes [soil fungi and nematodes, nitrite/nitrate conversion bacteria, biodegraders] and others of significance for improved sustainability [cellulolytic fungi, edible mushrooms, antagonistic fungi, arthropod natural enemies, entomopathogenic fungi, fungicolous fungi, toxin-producers].

ACTION 4: Develop training and educational aids for the identification of both the higher taxa of microorganisms and invertebrates, and also to lower levels in groups of particular importance, through well-illustrated manuals and interactive computerized systems.

Benefit: To provide scientists and teachers with the tools necessary to stimulate interest in biosystematics and to enable them to reliably ascertain at

least the major taxonomic groups to which organisms they encounter are referred.

Implementation: Commissioning the preparation of a plan to produce a suite of projects to provide data down to family level of all microorganism and invertebrate groups, including assessments as to the best delivery systems for developing country use. Each group project would then be contracted out piecemeal over 5-10 years as progress would be dependent on available expertise.

Note: Such systems would be unlikely to be able to cover a large number of groups down to species level in the foreseeable future, especially as so many are undescribed, but guides to higher groupings would be more practical and serve as an *entrée* into the specialist literature.

Refs: *Paras* 193-5.

ACTION 5: Develop checklists with preferred names to microorganisms and invertebrate groups, with type information where possible, and make these available in hard copy, CD-ROM or other searchable formats.

Benefit: To provide the basic taxonomic information required both in the production of national and regional inventories and in biosystematic research.

Implementation: Commission the production of rough drafts of accepted species names (with relevant bibliographic and typification details), in a standardized database format, for wide circulation and comment internationally. These would be amended in the light of comments received from specialists to produce information for sale on CD-ROM or in other formats updated periodically.

Note: The production of such lists should as far as practical be tied in with the current attempts of both botanists and zoologists to provide a more stable system of biological nomenclature.

Refs: *Paras* 155-158, 190-192.

ACTION 6: Implement compatible data capture, interrogation and transfer systems for collections in both developed and developing countries.

Benefit: To facilitate the transfer of information to developing countries of material present in developed country institutions, and also between countries and institutions in a region, and also enable that data to be used to greatest effect in biodiversity inventorying and management.

Implementation: Introduction of PC-based computerized data-capture systems into collections, using the exchange data formats developed by the IUBS Commission on Plant Taxonomic Databases. This would initially be for current accessions to limit the escalation of the problem, but could be added to retroactively as resources permitted. Developed country institutions would then be able to repatriate data when required at a modest cost.

Refs: *Paras* 153, 187-189.

ACTION 7: Assist developing countries in the introduction of microbial isolation, culture preservation, and co-operative screening programmes.

Benefit: To provide national or regional centres in developing countries with the capability of conducting large-scale isolation programmes for both, biodiversity studies and exploitation.

Implementation: Identification of target centres with some basic equipment and institutional commitment, training in isolation and preservation procedures, and advising on the drawing up of contracts with agrochemical and pharmaceutical companies in order to safeguard indigenous property rights. Local screening for microorganisms with particular could be undertaken using specific DNA probes or other media-based tests developed by companies for that purpose.

Refs: *Paras* 131-137 .

ACTION 8: Develop bioindication systems for the assessment of ecosystem health, particularly for the detection of environmental perturbations.

Benefit: Introduction of a low-cost appropriate-technology early-warning systems to detect threats to biodiversity maintenance in particular sites of conservation importance -- before the changes become irreversible.

Implementation: Design of bioindicator kits for use by reserve managers, environmental officers and other specialists. Testing the kits in field situations, and training trainers in their use so that they can be widely disseminated with instructions in appropriate languages.

Refs: *Paras* 73-85.

ACTION 9: Develop biochemical and molecular techniques for the detection and quantification of microorganisms crucial to the maintenance of biodiversity.

Benefit: Development of technologies to improve the accuracy of detection and assessment methods for microorganisms playing keystone roles in the maintenance of ecosystems.

Implementation: Fund research programmes to develop molecular probes for the detection of particular mycorrhizal fungi in soils, key functions related to nutrient fixation and cycling in bacteria and fungi (e.g. nitrogen fixation, nitrite/nitrate conversions, lingo-cellulose breakdown), and for the separation of morphologically similar organisms of importance in crop protection and quarantine.

Note: Placed as a lower priority in view of the lead times involved to applications in developing countries, but of immense importance in the longer term.

Refs: *Paras* 87-91, 96, 102, 105, 112-113, 146.

ACTION 10: Support, and where necessary initiate, MSc and PhD programmes on the biosystematics of microorganisms and invertebrates between the major biosystematic centres and universities in the UK and developing countries.

Benefit: Development of a cadre of appropriately skilled scientists in developed and developing countries to ensure the next generation of biosystematists is produced.

Implementation: Funding studentships on established courses and earmarking "quota" studentships linked to key biosystematic centres. The project and thesis topics to be considered in relation to the development of BIONET LOOPS (**Action 1**) in the case of developing countries, and to skills-gaps in relation to developed country institutions.

Refs: *Paras* 162, 169-70, 197.

Literature Cited

- Advisory Board for the Research Councils (1979) *Taxonomy in Britain*. London: HMSO.
- Aguilar, A. (1990) *European Laboratory Without Walls. MINE, the Microbial Information Network Europe*. Brussels: CEC.
- Ainsworth, A.M. & Hawksworth, D.L. (eds) (1992) *Biodiversity in the Caribbean*. Wallingford: CAB International.
- Alexander, H.M. (1992) Fungal pathogens and the structure of plant populations and communities. In: Carroll, G.C. & Wicklow, D.T. (eds), *The Fungal Community*: 481-497. New York: Marcel Dekker.
- Allen, M.F. (1991) *The Ecology of Mycorrhizae*. Cambridge: Cambridge University Press.
- Anon. (1982) Weevil worth \$115 million pa. *CAB News* 14:1.
- (1986) Report of the expert consultation on progress and problems in controlling fruit fly infestation, Bangkok, 1986. *RAPA Publication* 1986 (28): 1-18. Bangkok: FAO Regional Office for Asia and the Pacific.
- Appanah, S. (1987) Insect pollinators and the diversity of dipterocarps. In: A.J.G.H. Kostermans (ed.), *Proceedings of the Third Round Table Conference on Dipterocarps*: 277-291. Jakarta: UNESCO.
- Arnett, R.H. & Samuelson, G.A. (1986) *The Insect and Spider Collections of the World*. Gainesville: E.J. Brill.
- Arnolds, E. (1991) Mycologists and nature conservation. In: Hawksworth, D.L. (ed.), *Frontiers in Mycology*: 243-264. Wallingford: CAB International.
- Askew, R.R. (1971) *Parasitic Insects*. London: Heinemann Educational.
- Bagine, R.K.N., Watson, G.W. & Mungai, M.N. (1993) Exotic pests in Africa: problems of identification in interception and control. *Insect Science and Its Application*: in press.
- Batra, L.R. & Batra, S.W.T. (1979) termite-fungus mutualism. In: Batra, L.R. (ed.), *Insect-Fungus Symbiosis: Nutrition, Mutualism and Commensalism*: 117-163. New York: John Wiley & Sons.
- Beattie, A.J. (1985) *The Evolutionary Ecology of Ant-Plant Mutualisms*. New York: Cambridge University Press.
- de Barjac, H. & Sutherland, D.J. (eds) (1990) *Bacterial Control of Mosquitos & Blackflies*. New Brunswick: Rutgers University Press.
- Bates, J.W. & Farmer, A.M. (eds) (1992) *Bryophytes and Lichens in a Changing Environment*. Oxford: Clarendon Press.
- Bisby, F.A. & Hawksworth, D.L. (1991) What must be done to save systematics? In: Hawksworth, D.L. (ed.), *Improving the Stability of Names: Needs and Options*: 323-336. [Regnum Vegetabile No. 123.] Königstein: Koeltz Scientific Books.
- Bisett, J. & Borkent, A. (1988) Ambrosia galls: the significance of fungal nutrition in the evolution of the *Cecidomyiidae* (Diptera). In: Pirozynski, K.A. & Hawksworth, D.L. (eds), *Coevolution of Fungi with Plants and Animals*: 203-225. London: Academic Press.
- Blackwell, M. (ed.) (1988) *Mycological Society of America. Membership Directory and Handbook*. 51 pp. Baton Rouge: Mycological Society of America.
- Bond, W.J. & Slingsby, P. (1984) Collapse of an ant-plant mutualism: the Argentine ant (*Iridomyrmex humilis*) and myrmecochorous Proteaceae. *Ecology* 65: 1031-1037.
- Bradbury, J.F. (1986) *Guide to Plant Pathogenic Bacteria*. Slough: CAB International.

- Brasier, C.M. & Rayner, A.D.M. (1986) Whither terminology below the species level in the fungi ? In: Rayner, A.D.M., Brasier, C.M. & Moore, D. (eds), *Evolutionary Biology of the Fungi*: 379-388. Cambridge: Cambridge University Press.
- Bridge, P.D., Kozakiewicz, Z. & Paterson, R.R.M. (1992) PENIMAT: a computer assisted identification scheme for terverticillate *Penicillium* isolates. *Mycological Papers* **165**: 1-59.
- Brunt, A., Crabtree, K. & Gibbs, A. (eds) (1990) *Viruses of Tropical Plants*. Wallingford: CAB International.
- Bull, A.T. (1991) Biotechnology and biodiversity. In: Hawksworth, D.L. (ed.), *The Biodiversity of Microorganisms and Invertebrates: Its Role in Sustainable Agriculture*: 203-227. Wallingford: CAB International.
- , Goodfellow, M. & Slater, J.H. (1992) Biodiversity as a source of innovation in biotechnology. *Annual Review of Microbiology* **46**: 219-252.
- Burdon, J.J. & Leather, S.R. (eds) (1990) *Pests, Pathogens and Plant Communities*. Oxford: Blackwell Scientific Publications.
- Buyck, B. & Hennebert, G.L. (1992) *Directory of African Mycology. Répertoire de la Mycologie Africaine*. Louvain la Neuve: International Mycological Association & Mycothèque de l'Université Catholique de Louvain.
- Cherrett, J.M. (1989) Leaf-cutting ants. In: Lieth, H. & Werger, M.J.A. (eds), *Tropical Rain Forest Ecosystems: Biogeographical and Ecological Studies. Ecosystems of the World 14B*: 473-488. Amsterdam: Elsevier.
- Claridge, M.F. & Ingrouille, M. (1992) Systematic Biology and Higher Education in the UK. In: *Taxonomy in the 1990's*: 39-48. London: Linnean Society.
- Clay, K. (1992) Mycophyllas and mycorrhizas: comparisons and contrasts. In: Read, D.J., Lewis, D.H., Fitter, A.H. & Alexander, I.J. (eds), *Mycorrhizas in Ecosystems*: 13-25. Wallingford: CAB International.
- Coddington, J.A., Griswold, C.E., Silva, D., Pearanda, E. & Larcher, S.F. (1991) Designing and testing sampling protocols to estimate biodiversity in tropical ecosystems. In: Dudley, E.C. (ed.), *The Unity of Evolutionary Biology: Proceedings of the International Congress of Systematic and Evolutionary Biology*: 1-5. College Park: Dioscorides Press.
- Courrier, P. (ed.) (1992) *Global Biodiversity Strategy*. Washington, D.C.: World Resources Institute, IUCN and UNEP.
- CSIRO (1970) *The Insects of Australia. A Textbook for Students and Research Workers*. Carlton, Victoria: Melbourne University Press.
- Danks, H.V. (1988) Systematics in support of entomology. *Annual Review of Entomology* **33**: 271-296.
- DaSilva, E.J. (1991) Biotechnologies, microbes and the environment. *Nature & Resources* **27**(3): 23-29.
- , Kalakoutskii & Song, D.-k. (1991) Microbial germ plasm resources. *Impact of Science on Society* **158**: 155-165.
- Daume, P. (1991) *1991 Britannica Book of the Year*. Chicago: Encyclopaedia Britannica.
- Davies, K.G., de Leij, F.A.A.M. & Kerry, B.R. (1991) Microbial agents for the biological control of plant-parasitic nematodes in tropical agriculture. *Tropical Pest Management* **37**: 303-320.
- de Bruyn, L.A.L. & Conacher, A.J. (1990) The role of termites and ants in soil modification: a review. *Australian Journal of Soil Research* **28**: 55-93.
- Desai, W.B. & Peerally, M.A. (1992) Taxonomic and genetical studies of *Coprinus castaneus* Berk. & Berk., a new indigenous mushroom from Mauritius. In: Hennebert, G.L. (ed.), *Aspects of African Mycology*: 81-91. Louvain-la-Neuve: International Mycological Association.
- Di Castri, F., Robertson-Vernhes, J. & Younes, T. (1992) A proposal for an international network on inventorying and monitoring of biodiversity. *Biology International, Special Issue* **27**: 1-27.
- Dowell, R.V. & Wange, L.K. (1986) Process analysis and failure avoidance in fruit fly programmes, In: Mangel, M., Carey, J.R., & Plant, R.E. (eds),

- Pest Control: operations and systems in fruit fly management* [NATO Advanced Science Institutes Series G: Ecological Sciences, vol. 11.]: 43-65. Berlin: Springer Verlag.
- Erwin, T.L. (1982) Tropical forests: their richness in *Coleoptera* and other arthropod species. *Coleopterist's Bulletin* 36: 74-75.
- Faith, D.P. (1992) Conservation evaluation and phylogenetic diversity. *Biological Conservation* 61: 1-10.
- Farrington, J. & Greeley, M. (1989) The issues. In: Farrington, J. (ed.), *Agricultural Biotechnology: Prospects for the Third World*: 7-26. London: Overseas Development Institute.
- Fischer, R.L., Knight, K.L., Michener, C.D., Moss, W.W., Oman, P., Powell, J.A. & Hurd, P.D. (1974) Report of the Advisory Committee for Systematics Resources in Entomology. *Bulletin of the Entomological Society of America* 20: 237-242.
- Frisvad, J.C. & Filtenborg, O. (1990) Secondary metabolites as consistent criteria in *Penicillium* taxonomy and a synoptic key to *Penicillium* subgenus *Penicillium*. In: Samson, R.A. & Pitt, J.A. (eds), *Modern Concepts in Penicillium and Aspergillus Classification*: 373-384. New York: Plenum Press.
- Gams, W. (1992) The analysis of communities of saprophytic microfungi with special reference to soil fungi. In: Winteroff, W. (ed.), *Fungi in Vegetation Science*: 183-223. Dordrecht: Kluwer Academic.
- Gaston, K.J. (1991) The magnitude of global insect species richness. *Conservation Biology* 5: 283-296.
- & May, R.M. (1992) Taxonomy of taxonomists. *Nature* 356: 281-282.
- [Gilbert, O.L.] (1989) The greenhouse effect and lichens. *British Lichen Society Bulletin* 65: 1-5.
- Giller, K.E. & Wilson, K.J. (1991) *Nitrogen Fixation in Tropical Cropping Systems*. Wallingford: CAB International.
- Gray, J.M. (1991) *British Lichen Society Membership List*. London: British Lichen Society.
- Groombridge, B. (ed.) 1992. *Global Biodiversity: Status of the Earth's Living Resources*. London: Chapman & Hall.
- Hall, G.S. & Hawksworth, D.L. (1990) *International Mycological Directory*. Second edition. Wallingford: CAB International.
- Hamer, M., Coghlan, A., Toto, T., Joyce, C. & Anderson, I. (1990) Will taxonomy go the way of the dinosaurs? *New Scientist* 126 (1722): 32-33.
- Hammond, P.M. (1990) Insect abundance and diversity in the Dumoga-Bone National Park, N. Sulawesi, with special reference to the beetle fauna of lowland rain forest in the Toraut region. In: Knight, W.J. & Holloway, J.D. (eds), *Insects in the Rain Forests of South East Asia (Wallacea)*: 197-254. London: Royal Entomological Society.
- (1992) Species inventory. In: Groombridge, B. (ed.), *Global Biodiversity: Status of the Earth's Living Resources*: 17-39. London: Chapman & Hall.
- & Lawrence, J.F. (1989) Mycophagy in insects: a summary. In: Wilding, N., Collins, N.M., Hammond, P.M. & Webber, J.F. (eds), *Insect-Fungus Interactions*: 275-324. London: Academic Press.
- Hancock, E.G. & Morgan, P.J. (1980) *A Survey of Zoological and Botanical Material in Museums and other Institutions of Great Britain*. Cardiff: Biology Curators Group.
- Haskell, P.T. & Morgan, P.J. (1988) User needs in systematics and obstacles to their fulfilment. In: Hawksworth, D.L. (ed.), *Prospects in Systematics*: 399-413. Oxford: Clarendon Press.
- Hawksworth, D.L. (1985) Fungus culture collections as a biotechnological resource. *Biotechnology and Genetic Engineering Reviews* 3: 417-453.
- (1991a) The fungal dimension of biodiversity: magnitude, significance, and conservation. *Mycological Research* 95: 641-655.

- (ed.) (1991b) *The Biodiversity of Microorganisms and Invertebrates: Its Role in Sustainable Agriculture*. Wallingford: CAB International.
- (1991c) Biological diversity in fungi, bacteria and viruses. *Biology Education* 8: 57-62.
- (1992a) Biodiversity in microorganisms and its role in ecosystem function. In: Solbrig, O.T., van Emden, H.M. & van Oordt, P.G.W.J. (eds), *Biodiversity and Global Change*: 83-93. Paris: IUBS.
- (1992b) Microorganisms. In: Groombridge, B. (ed.), *Global Biodiversity: Status of the Earth's Living Resources*: 47-52. London: Chapman & Hall.
- (1993a) The tropical fungal biota: census, pertinence, prophylaxis, and prognosis. In: Isaac, S., Watling, R., Whalley, A.J. & Frankland, J.C. (eds), *Tropical Mycology*: in press. Cambridge: Cambridge University Press.
- (1993b) Litmus tests for ecosystem health: The potential of bioindicators in the monitoring of biodiversity. In: Swaminathan, M.S. & S. Jana (eds), *Biodiversity: implications for global food security*: in press. Macmillan India.
- & Ahti, T. (1990) A bibliographic guide to the lichen floras of the world (second edition). *Lichenologist* 22: 1-78.
- & Colwell, R.R. (eds) (1992) Biodiversity amongst microorganisms and its relevance. *Biodiversity and Conservation* 1: 219-345.
- & Hill, D.J. (1984) *The Lichen-Forming Fungi*. Glasgow: Blackie & Sons.
- & Mound, L.A. (1991) Biodiversity databases: the crucial significance of collections. In: Hawksworth, D.L. (ed.), *The Biodiversity of Microorganisms and Invertebrates: Its Role in Sustainable Agriculture*: 17-29. Wallingford: CAB International.
- Heywood, V.H. & Clark, R.B. (1982) *Taxonomy in Europe. Final Report*. Amsterdam: North Holland Publishing.
- Hodkinson, I.D. & Casson, D. (1991) A lesser predilection for bugs: *Hemiptera* (insects) diversity in tropical rain forests. *Biological Journal of the Linnean Society* 43: 101-109.
- Holden, C. (1989) Entomologists wane as insects wax. *Science* 246: 754-756.
- Holdom, D.G., Taylor, P.S., Mackay-Wood, R.J., Ramos, M.E. & Roper, R.S. (1989) Field studies on rice planthoppers (*Hom.*, *Delphacidae*) and their natural enemies in Indonesia. *Journal of Applied Entomology* 107: 118-129.
- Holguin, G., Guzman, M.A. & Bashan, Y. (1992) Two new nitrogen-fixing bacteria from the rhizosphere of mangrove trees: their isolation, identification and in vitro interaction with rhizosphere *Staphylococcus* sp. *FEMS Microbiology Ecology* 101: 207-216.
- Holldobler, B. & Wilson, E.O. (1990) *The Ants*. Cambridge, Mass.: Belknap Press.
- Holliday, P. (1980) *Fungus Diseases of Tropical Crops*. Cambridge: Cambridge University Press.
- Holloway, J.D. & Barlow, H. (1983) The role of taxonomy, reference works and insect collections in tropical ecology. *Antenna* 7: 50-53.
- & ----- (1992) Potential for loss of biodiversity in Malaysia, illustrated by the moth fauna. In: Barlow, H.S. & Aziz Kadir, A. (eds), *Pest management and the environment in the year 2000*: 293-311. Wallingford: CAB International.
- & Stork, N.E. (1991) The dimensions of biodiversity: the use of invertebrates as indicators of human impact. In: Hawksworth, D.L. (ed.), *The Biodiversity of Microorganisms and Invertebrates: Its Role in Sustainable Agriculture*: 37-62. Wallingford: CAB International.
- Holmgren, P.K., Holmgren, N.H. & Barnett, L.C. (1990) *Index Herbariorum. Part 1: The Herbaria of the World*. Eighth edition. [Regnum Vegetabile No. 120.] New York: New York Botanical Garden.
- House of Lords Select Committee on Science and Technology (1992) *Systematic Biology Research*. [HL Paper 22-1.] London: HMSO.

- Isley, D. (1972) The Disappearance. *Taxon* 21: 3-12.
- Janzen, D.H. (1987) How moths pass the dry season in a Costa Rican dry forest. *Insect Science and its Application* 8 (4-6): 489-500.
- Jeffrey, D.W. & Madden, B. (eds) (1991) *Bioindicators and Environmental Management*. London: Academic Press.
- Johnston, A. & Booth, C. (eds) (1983) *Plant Pathologist's Pocketbook*. 2nd edition. Slough: Commonwealth Agricultural Bureaux.
- Jones, T. (1992) BIONET - the concept for an international network to support regional and national biosystematic services. In: Ainsworth, A.M. & Hawksworth, D.L. (eds), *Biodiversity in the Caribbean*: 15-24. Wallingford: CAB International.
- Kantvilas, G., James, P.W. & Jarman, S.J. (1985) Macrolichens in Tasmanian rainforests. *Lichenologist* 17: 67-83.
- Kartohardjono, A. & Heinrichs, E.A. (1984) Populations of the Brown Planthopper, *Nilaparvata lugens* (Stal) (Homoptera: Delphacidae), and its predators on rice varieties with different levels of resistance. *Environmental Entomology* 13: 359-365.
- Kelley, J. (1992) Upgrading of waste cereal straws. *Outlook on Agriculture* 21: 105-108.
- Khan, R.A. & Thulin, J. (1991) Influences of pollution on parasites of aquatic animals. *Advances in Parasitology* 30: 200-238.
- Kim, K.C. (1989) Formation of Entomology Collections Network (ECN). *Insect Collection News* 2(2): 1-2.
- Knutson, L. (1981) Symbiosis of biosystematics and biological control. In: Papavizas, G.C. (ed.), *Biological Control in Crop Production*: 61-78. Dordrecht: Kluwer Academic Publishing.
- Kowalski, S. (1980) Influence of soil fungus community in selected mountain stands on the development of *Cylindrocarpon destructans* (Zins.) Scholt. *Acta Societatis Botanica Polonica* 49: 487-492.
- Kumar, R. (1981) The case for the establishment of an insect identification service and taxonomic research centre(s) in Africa. *Insect Science and Its Application* 1: 425-430.
- (1987) University training of entomologists, especially taxonomists, in tropical Africa. *Insect Science and its Application* 8: 927-935.
- LaSalle, J. (1993) Parasitic Hymenoptera, biological control, and biodiversity. In: LaSalle, J. & Gauld, I.D. (eds), *Hymenoptera and Biodiversity*: 197-215. Wallingford: CAB International.
- & Gauld, I.D. (1992) ["1991"] Parasitic Hymenoptera and the biodiversity crisis. *Redia* 74 (3) [Appendix]: 315-334.
- & ----- (1993) Hymenoptera: their diversity, and their impact on the diversity of other organisms. In: LaSalle, J. & Gauld, I.D. (eds), *Hymenoptera and Biodiversity*: 1-26. Wallingford: CAB International.
- Lavelle, P. (1988) Assessing the abundance and role of invertebrate communities in tropical soils: aims and methods. *Revue de Zoologie Africaine* 1988: 275-283.
- Ledig, F.T. (1992) Human impacts on genetic diversity in forest ecosystems. *Oikos* 63: 87-108.
- Lee, K.E. (1991) The Diversity of Soil organisms. In: Hawksworth, D.L. (ed.), *The Biodiversity of Microorganisms and Invertebrates: Its Role in Sustainable Agriculture*: 73-87. Wallingford: CAB International.
- & Wood, T.G. (1971) *Termites and Soils*. New York: Academic Press.
- Lenat, D.R. (1988) Water quality assessment of streams using a quantitative collection method for benthic macroinvertebrates. *Journal of the North American Benthological Society* 7: 222-233.
- Lichtenfels, J.R. & Pritchard, M.H. (1982) *A Guide to the Parasite Collections of the World*. American Society of Parasitologists.
- Lovelock, J.E. (1992) A numerical model for biodiversity. *Philosophical Transactions of the Royal Society of London, B*, 338: 383-391.

- Lugo, A. (1988) Diversity of tropical species: questions that elude answers. *Biology International, Special Issue 19*: 1-37.
- Lynch, J.M. & Hobbie, J.E. (eds) (1988) *Microorganisms in Action: Concepts and Applications in Microbial Ecology*. Second edition. Oxford: Blackwell Scientific Publications.
- McGowan, V.F. & Skerman, V.B.D. (1986) *World Catalogue of Rhizobium Collections*. Third edition. St Lucia: World Data Center for Microorganisms.
- Magurran, A.E. (1988) *Ecological Diversity and its Measurement*. London: Croom Helm.
- Maher, W.A. & Norris, R.H., (1990) Water quality assessment programmes in Australia. Deciding what to measure, and how and where to use bioindicators. *Environmental Monitoring and Assessment 14*: 115-130.
- Martin, M.M. (1987) *Invertebrate-Microbial Interactions. Ingested Fungal Enzymes in Arthropod Biology*. Ithaca: Comstock Publishing.
- Mayr, E. (1969) *Principles of Systematic Zoology*. New York: McGraw-Hill.
- Medler, J.T. (1980) Insects of Nigeria - checklist and bibliography. *Memoirs of the American Entomological Institute 30*: i-viii, 1-919.
- Mishler, B.D. & Donoghue, M.J. (1992) Species concepts: a case for pluralism. In: Ereshefsky, M. (ed.), *The Units of Evolution. Essays on the Nature of Species*: 121-137. Cambridge, Mass.: MIT Press.
- Morgan, P.J. (ed.) (1986) *A National Plan for Systematic Collections ?* Cardiff: National Museum of Wales.
- Morton, J., Franke, M. & Cloud, G. (1992) The nature of fungal species in *Glomales* (zygomycetes). In: Read, D.J., Lewis, D.H., Fitter, A.H. & Alexander, I.J. (eds), *Mycorrhizas in Ecosystems*: 65-73. Wallingford: CAB International.
- Muddiman, S.B., Hodkinson, I.D. & Hollis, D. (1991) Legume feeding psyllids of the genus *Heteropsylla* (Homoptera: Psylloidea). *Bulletin of Entomological Research 82*: 73-117.
- Muller, R. & Baker, J.R. (1988) The demands of medicine and veterinary science. In: Hawksworth, D.L. (ed.), *Prospects in Systematics*: 377-395. Oxford: Clarendon Press.
- Myers, J.H., Higgins, C. & Kovacs, E. (1988) How many insect species are necessary for the biological control of insects? *Environmental Entomology 18*: 541-547.
- Myers, N. (1990) The biodiversity challenge: expanded hot-spots analysis. *The Environmentalist 10*(4): 1-14.
- Nash, T.H. III & Wirth, V. (eds) (1988) *Lichens, Bryophytes and Air Quality*. [Bibliotheca Lichenologica Vol. 30.] Berlin: J. Cramer.
- Natural Environment Research Council (1992) *Evolution and Biodiversity: the New Taxonomy*. London: Natural Environment Research Council.
- Nestel, D., Dicksen, F. & Altieri, M.A. (1993) Diversity patterns of soil macro-Coleoptera in Mexican shaded and unshaded coffee agroecosystems: an indication of habitat perturbation. *Biodiversity and Conservation 2*: 70-78.
- Nisbet, L.J. & Fox, F.M. (1991) The importance of microbial biodiversity to biotechnology. In: Hawksworth, D.L. (ed.), *The Biodiversity of Microorganisms and Invertebrates: Its Role in Sustainable Agriculture*: 229-244. Wallingford: CAB International.
- Norrsgard, R.B. (1988) The biological control of cassava mealybug in Africa. *American Journal of Agricultural Economics 70*: 366-371.
- O'Toole, C. (1993) Diversity of native bees and agroecosystems. In: LaSalle, J. & Gauld, I.D. (eds), *Hymenoptera and Biodiversity*: 169-196. Wallingford: CAB International.
- Overseas Development Administration (1991) *Biological Diversity and Developing Countries*. London: ODA.

- Paoletti, M.G., Favretto, M.R., Stinner, B.R., Purrington, F.F. & Bater, J.E. (1991) Invertebrates as bioindicators of soil use. *Agriculture, Ecosystems and Environment* **34**: 341-362.
- Parlevliet, J.E. (1986) Coevolution of host resistance and pathogen virulence: possible implications for taxonomy. In: Stone, A.R. & Hawksworth, D.L. (eds), *Coevolution and Systematics*: 19-34. Oxford: Clarendon Press.
- Pascoe, I.G. (1990) History of systematic mycology in Australia. In: Short, P.S. (ed.), *History of Systematic Botany in Australia*: 259-264. South Yarra: Australian Systematic Botany Society.
- Patrick, R. (1973) Use of algae, especially diatoms, in the assessment of water quality. *American Society for Testing and Materials, Special Technical Publication* **528**: 76-95.
- Perry, D.A., Amaranthus, M.P., Borchers, J.G., Borchers, S.L. & Brainerd, R.E. (1989) Bootstrapping in ecosystems. *BioScience* **39**: 230-237.
- Pirozynski, K.A. & Malloch, D.W. (1988) Seeds, spores and stomachs: coevolution in seed dispersal mutualisms. In: Pirozynski, K.A. & Hawksworth, D.L. (eds), *Coevolution of Fungi with Plants and Animals*: 227-246. London: Academic Press.
- Poinar, G.O. (1983) *The Natural History of Nematodes*. Englewood Cliffs, New Jersey: Prentice Hall.
- Prance, G.T. (1976) The pollination and androphore structure of some Amazonian *Lecythidaceae*. *Biotropica* **8**: 235-241.
- Price, P.W. (1988) An overview of organismal interactions in ecosystems in evolutionary and ecological time. *Agriculture, Ecosystems and Environment* **24**: 369-377.
- Prior, C. (1989) Biological pesticides for low external-input agriculture. *Biocontrol News and Information* **10**: 17-22.
- Read, D.J. (1991) Mycorrhizas in ecosystems - nature's response to the "Law of the Minimum". In: Hawksworth, D.L. (ed.), *Frontiers in Mycology*: 101-130. Wallingford: CAB International.
- , Lewis, D.H., Fitter, A.H. & Alexander, I.J. (eds) (1992) *Mycorrhizas in Ecosystems*. Wallingford: CAB International.
- Richardson, D.H.S. (1992) *Pollution Monitoring with Lichens*. [Naturalists' Handbooks No. 19.] Slough: Richmond Publishing.
- Ritchie, J.M. (1987) Insect biosystematic services in Africa: current status and future prospects. *Insect Science and its Application* **8**: 425-432.
- (1992) International support for Caribbean biosystematics services. In: Ainsworth, A.M. & Hawksworth, D.L. (eds), *Biodiversity in the Caribbean*: 41-43. Wallingford: CAB International.
- Roger, P.A., Heong, K.L. & Teng, P.S. (1991) Biodiversity and sustainability of wetland rice production: role and potential of microorganisms and invertebrates. In: Hawksworth, D.L. (ed.), *The Biodiversity of Microorganisms and Invertebrates: Its Role in Sustainable Agriculture*: 117-136. CAB International.
- Rose, F. (1992) Temperate forest management: its effects on bryophyte and lichen floras and habitats. In: Bates, J.W. & Farmer, A.M. (eds), *Bryophytes and Lichens in a Changing Environment*: 211-233. Oxford: Clarendon Press.
- Round, F.E. (1991) Diatoms in river water-monitoring studies. *Journal of Applied Phycology* **3**: 129-145.
- Russell-Smith, A. & Stork, N. (1993) Diversity and abundance of spiders in the canopy of tropical rain forests in Sulawesi. *Journal of Tropical Ecology*: in press.
- Sands, W.A. (1981) Identification services for Africa. *Insect Science and its Application* **1**: 443-444.
- Sailer, R. (1983) History of insect introductions. In: Wilson, C.L. and Graham, C.L. (eds), *Exotic plant pests and North American Agriculture*: 15-38. New York: Academic Press.

- Sasser, J.N. (1979) Economic importance of *Meloidogyne* in tropical countries. In: Lamberti, F. & Taylor, C.E. (eds), *Root-knot nematodes (Meloidogyne species)*: 359-374. London: Academic Press.
- Sawyer, W.D. (1984) Summary and recommendations. In: Sawyer, W.D. (ed.), *Biotechnology for the Americas: Prospects for Developing Countries*: 77-79. Washington, D.C.: Interciencia Association.
- Scholtz, C.H. & Holm, E. (1985) *Insects of Southern Africa*. Surban: Butterworths.
- Scott, P.R. (1991) The universal issue: information transfer. In: Hawksworth, D.L. (ed.), *The Biodiversity of Microorganisms and Invertebrates: Its Role in Sustainable Agriculture*: 245-266. Wallingford: CAB International.
- Shepard, B.M., Rapusas, H.R., & Estano, D.B. (1989) Using rice straw bundles to conserve beneficial arthropod communities in rice fields. *International Rice Research News* 14(5): 30-31.
- Siddiqi, M.R. (1986) Pest risk analysis of nematodes in plant quarantine. In: Singh, K.G. & Manalo, P.L. (eds), *Proceedings of the Regional Conference on Plant Quarantine Support for Agricultural Development*: 243-252. Serdang: ASEAN Plant Quarantine Centre and Training Institute.
- Sims, R.W., Freeman, P. & Hawksworth, D.L. (eds) (1988) *Key Works to the Fauna and Flora of the British Isles and North-Western Europe*. Fifth edition. Oxford: Clarendon Press.
- Smalley, M.E. (1987) A model for a regional collaborative training programme in the insect sciences. *Insect Science and its Application* 8(4-6): 943-949.
- Smith, I.M., McNamara, D.G., Scott, P.R. & Harris, K.M. (eds) (1992) *Quarantine Pests for Europe*. Wallingford: CAB International.
- Smits, W.T.M. (1992) Mycorrhizal studies in dipterocarp forests in Indonesia. In: Read, D.J., Lewis, D.H., Fitter, A.H. & Alexander, I.J. (eds), *Mycorrhizas in Ecosystems*: 283-292. Wallingford: CAB International.
- Sohlenius, B. (1980) Abundance, biomass and contribution to energy flow by soil nematodes in terrestrial ecosystems. *Oikos* 34: 186-194.
- Solbrig, O.T. (ed.) (1991) *From Genes to Ecosystems: A Research Agenda for Biodiversity*. Cambridge, Mass.: IUBS.
- , van Emden, H.M. & van Oort, P.G.W.J. (eds) (1992) *Biodiversity and Global Change*. [IUBS Monograph No 8.] Paris: IUBS.
- Southwood, T.R.E. (1978) *Ecological Methods: With particular reference to the study of insect populations*. Second edition. New York: Chapman and Hall.
- Sprent, J.I. & Sprent, P. (1990) *Nitrogen Fixing Organisms*. London: Chapman & Hall.
- Starr, C.R. (1992) *Insect/Arachnid Collections in the Caribbean*. [Manuscript.] St Augustine: University of the West Indies.
- Steffen, W.L., Walker, B.K., Ingram, J.S. & Koch, G.W. (eds) (1992) *Global Change and Terrestrial Ecosystems. The Operational Plan*. [IGBP Global Change Report No. 21.] Stockholm: IGBP.
- Stork, N.E. (1988) Insect diversity: facts, fiction and speculation. *Biological Journal of the Linnean Society* 35: 321-337.
- Stork, N.E. & Brendell, M.J.D. (1993) Arthropod diversity studies in lowland rain forest of Seram: Indonesia. In: Edwards, I. & Proctor, J. (eds), *The Natural History of Seram*: in press. London: Fischer & Duncan.
- Subramanian, C.V. (1982) Tropical mycology: future needs and options. *Current Science* 51: 321-325.
- Swaminathan, M.S. (1990) Keynote Address. In: *Eleventh Review Conference London 1990. Report of Proceedings*: 11-18. Wallingford: CAB International.
- Takishima, Y., Shimura, J., Udagawa, Y. & Sugawara, H. (1989) *Guide to World Data Center on Microorganisms with a List of Culture Collections in the World*. Saitama: World Data Center on Microorganisms.

- Terborough, J. (1986) Keystone plant resources in the tropical forest. In: Soulé, M.E. (ed.), *Conservation Biology: the science of scarcity and diversity*: 330-344. Sunderland, Mass.: Sinauer Associates.
- Trappe, J.M. (1977) Selection of fungi for ectomycorrhizal inoculation in nurseries. *Annual Review of Phytopathology* 15: 203-222.
- Trüper, H.G. (1992) Prokaryotes: an overview with respect to biodiversity and environmental importance. *Biodiversity and Conservation* 1: 227-236.
- UNESCO (1962) *Directory of Zoological and Entomological specimen Collections of Tropical Institutions*. Paris: UNESCO.
- van der Wal, A.F. & de Goede, R.G.M. (eds) (1988) *Nematodes in Natural Systems*. Wageningen: Agricultural University.
- Vane-Wright, R.I. (1992) Species concepts. In: Groombridge, B. (ed.), *Global Biodiversity: Status of the Earth's Living Resources*: 13-16. London: Chapman & Hall.
- , Humphries, C.J. & Williams, P.H. (1991) What to protect? - Systematics and the agony of choice. *Biological Conservation* 55: 235-254.
- Vargas, M. & Hall, M.J.R. (1989) *Manual for the control of the screwworm fly Cochliomyia hominivorax, Coquerel*. Rome: FAO.
- Waage, J.K. (1991a) Biological control and biodiversity. *Biology Education* 8: 63-70.
- (1991b) Biodiversity as a resource for biological control. In: Hawksworth, D.L. (ed.), *The Biodiversity of Microorganisms and Invertebrates: Its Role in Sustainable Agriculture*: 149-162. Wallingford: CAB International.
- & Greathead, D.J. (1988) Biological control: challenges and opportunities. *Philosophical Transactions of the Royal Society of London, B*, 318: 111-128.
- Wainwright, M. (1992) The impact of fungi on environmental geochemistry. In: Carroll, G.C. & Wicklow, D.T. (eds), *The Fungal Community*: 601-618. New York: Marcel Dekker.
- Wakefield, A.E., Peters, S.E., Banerji, S., Bridge, P.D., Hall, G.S., Hawksworth, D.L., Guiver, L.A., Allen, A.G. & Hopkin, J.M. (1992) *Pneumocystis carinii* shows DNA homology with the ustomycetous red yeast fungi. *Molecular Microbiology* 6: 1903-1911.
- Waller, J. [M.] (1991) General Discussion: Session III. In: Hawksworth, D.L. (ed.), *The Biodiversity of Microorganisms and Invertebrates: Its Role in Sustainable Agriculture*: 197. Wallingford: CAB International.
- WATCH (1991) *National River Watch. The River Water Pack*. Slough: Richmond Publishing.
- Wheeler, Q.D. (1990) Insect diversity and cladistic constraints. *Annals of the Entomological Society of America* 83: 1031-1047.
- White, I.M. (1991) The application of tephritid taxonomy to problems in plant quarantine and weed biological control. In: Weissmann, L., Orszagh, I & Pont, A.C. (eds), *Proceedings of the Second International Congress of Dipterology, Bratislava, 1990*: 341-349. The Hague: SPB Academic Publishing.
- , & Elson-Harris, M.M. (1992) *Fruit Flies of Economic Significance: Their Identification and Bionomics*. Wallingford: CAB International.
- Whitton, B.A. (1992) Diversity, ecology, and taxonomy of the Cyanobacteria. In: Mann, N.H. & Carr, N.G. (eds), *Photosynthetic Prokaryotes*: 1-51. New York: Plenum Press.
- Wielemaker, W.G. (1984) *Soil formation by termites; a study in the Kisii area, Kenya*. Doctoral thesis, Agricultural University, Wageningen.
- Williams, B. (1987) *Biological Collections*. UK. The Museums Association.
- Wilson E.O. (1985) Time to revive systematics. *Science* 230: 1227.
- Wilson, J., Ingleby, K., Mason, P.A., Ibrahim, K. & Lawson, G.J. (1992) Long-term changes in vesicular-arbuscular mycorrhizal spore populations in *terminalia* plantations in Côte d'Ivoire. In: Read, D.J., Lewis, D.H.,

- Fitter, A.H. & Alexander, I.J.(eds), *Mycorrhizas in Ecosystems*: 268-275. Wallingford: CAB International.
- Wolseley, P.A. (1991) Observations on the composition and distribution of the *Lobarion* in forests of South East Asia. In: Galloway, D.J. (ed.), *Tropical Lichens: Their Systematics, Conservation and Ecology*: 217-243. Oxford: Clarendon Press.
- Wood, A.M. (1989) *Insects of Economic Importance: A Checklist of Preferred Names*. Wallingford: CAB International.
- World Federation for Culture Collections (1990) *Guidelines for the Establishment and Operation of Collections of Cultures of Microorganisms*. Campinas: WFCC.
- Wouts, W. (1991) *Steinernema (Neoaplectana)* and *Heterorhabditis* species. In: Nickle, W.R. (ed.), *Manual of Agricultural Nematology*. Basel & New York: Marcel Decker.
- Yasuno, M. & Whitton, B.A. (1986) Biological monitoring for aquatic pollution. In: Salanki, J. (ed.), *Biological Monitoring of the State of the Environment: Bioindicators*: 57-66. Oxford: IRL Press.
- Younès, T. (ed.) (1992) *Promoting Life Sciences for a better Human Life*. Paris: IUBS.

Annexes

- 1 Dried reference collections of fungi (including lichens) within tropical countries.
- 2 Living reference collections of bacteria and fungi (including yeasts) within tropical countries.
- 3 Preserved entomological reference collections within tropical countries.
- 4 Reference collections of plant nematodes and animal helminths within tropical countries.
- 5 Synopsis of numbers of reference collections of microorganisms and invertebrates within tropical countries.
- 6 Numbers of helminth and nematode identifications by the International Institute of Parasitology (CABI) 1983-1991.
- 7 Indicators of the resource base for mycological investigations within tropical countries (from Hawksworth, 1993a).
- 8 Numbers and geographical origin of trainees at CABI Institutes 1985-1992.
- 9 BIONET - the concept for an international network to support regional and national biosystematic services (from Jones, 1992).

Annex 1 Dried reference collections of fungi (including lichens) within tropical countries

Location		Number of specimens (where known)
Africa		
Algeria*		
Angola		
Benin		
Botswana		
Burkina Faso		
Burundi	Univ du Burundi, Fac des Sci, Bujumbura	600
Cameroon		
Cape Verde Islands		
Central African Republic		
Chad		
Comoros		
Congo	ORSTOM, Lab de Phytopath, Brazzaville	in creation
Côte d'Ivoire	ENSA, Lab de Phytopath, Yamoussoukro	40
Djibouti		
Egypt*	Univ of El Minia, El Minia	20
Equatorial Guinea		
Ethiopia	Debre Zeit Agric Res Cen, Debre Zeit	100
Gabon		
Gambia		
Ghana	CSRI, Crops Res Inst, Kumasi	rudimentary
	Botany Dept., Univ of Cape Coast, Cape Coast	-
	Ghana Mycological Herbarium, Univ of Ghana, Legon	-
Guinea	IRAG, Centre de Res Agron de Foulaye, Guinée Maritime	53
Guinea Bissau		
Kenya	Botany Dept, University of Nairobi, Nairobi	-
	National Museum of Kenya, Nairobi	-
	(some currently at KARI, Muguga)	
	KARI, Nairobi	2000
Lesotho		
Liberia		
Libya*		
Madagascar	Dept Botanique, Parc de Tsimbazaza, Antananarivo	-
	CENRADERU-FO.FL.FA., Ambatobe	1000
Malawi		
Mali*		
Mauritania*		
Mauritius	Mauritius Sugar Research Institute, Réduit	-
Mayotte		
Mozambique		
Namibia		
Niger		
Nigeria	Botany & Microbiology Dept, Univ of Ibadan, Ibadan	-
	Lab of Mycology, Univ of Nigeria, Nsukka	small
	Botany Dept, Univ of Nigeria, Nsukka	-
	Ogun State Univ, Ago-Iwoye	800
	Univ of Benin, Ugbowo campus, Benin City	250
	Univ of Jos, Bauchi Road campus, Jos	250
	Univ of Jos, Med Micro & Myc, Jos Plateau State, Jos	20

Annex 1 Dried reference collections of fungi (including lichens) within tropical countries

	Location	Number of specimens (where known)
	Bayero Univ, Biol Sci, Kano	30
	Fed Univ of Technology, Lake Nwaeber Campus, Owerri	20
Réunion		
Rwanda	Inst des Sci Agron du Rwanda, Dep de Prod Veg, Butare	15
Saint Helena & Ascension		
Sao Tome & Principe		
Senegal	Inst Sci Res Agron, Lab of Phytopath, Dakar	small
Seychelles		
Sierra Leone	University of Sierra Leone, Freetown	-
Somalia		
South Africa*	Botany Dept, Univ of the North, Pietersburg	-
	Plant Sci Dept, Potchefstroom University, Potchefstroom	-
	Plant Protection Research Institute, Pretoria	50 000
	Univ of Pretoria, Dept of Botany, Pretoria	1500
	Outspan Citrus Centre, Nelspruit	12
	Univ of Natal, Dept of Microb & Plant Path, Pietermaritzburg	50
	Univ of Durban-Westville, Dept of Bot, Durban	varied
	Univ of Natal, Dept of Biology, Durban	300
	Univ of Stellenbosch, Dept of Plant Path, Stellenbosch	300
	Univ of Orange Free State, Lab of Tree Path & Mycol, Bloemfontein	varied
Sudan, The		
Swaziland		
Tanzania		
Togo		
Uganda	Botany Dept, Makerere University, Kampala	-
Zaire	Univ de Kinshasa, Fac des Sci, CRAT, Kinshasa	50
Zambia		
Zimbabwe	Forestry Commission, Highlands, Harare	3000
	Biol Sci, Univ of Zimbabwe, Harare	-
	c/o Mme C. Sharp, Beacon Hill, Mvuma	1000
Asia		
Bangladesh*		
Brunei		
Cambodia		
Hong Kong		
India*	Botany Dept., University of Burdwan, Burdwan	-
	Botany Dept, Panjab Univ, Chandigarh	-
	Tamil Nadu Agric Univ, Coimbatore	[1600]
	Botanical Survey of India, Sikkim Himalayan Circle, Gangtok	-
	National Botanical Research Institute, Lucknow	-
	Botany Dept, University of Lucknow, Lucknow	-
	Botany Dept, University of Delhi, New Delhi	-
	Indian Agricultural Research Institute, New Delhi	41 000
	Botany Dept, Punjabi University, Patiala	-
	Maharashtra Assoc for the Cultivation of Science Research Inst, Pune	27 000
	Botanical Survey of India, Eastern Circle, Shillong	-
	Institute of Agricultural Sciences, Varanasi	2500
Indonesia	Herbarium Bogoriense, Bogor	-
Laos		
Malaysia	Universiti Kebangsaan Malaysia, Bangi	-
	University of Malaya, Kuala Lumpur	-

Annex 1 Dried reference collections of fungi (including lichens) within tropical countries

Location		Number of specimens (where known)
Maldives		
Myanmar/Burma		
Oman	Natural History Museum, Muscat	-
People's Republic of China*	Institute of Microbiology, Academia Sinica, Beijing	75 000
	Hunan Biology Institution, Changsha	-
	Sichuan Institute of Chinese Materia Medica, Chongqing	-
	Zhongshan (Sun Yatsen) University, Guangzhou	-
	Hangzhou University, Hangzhou	-
	University of Inner Mongolia, Hohhot	-
	Kunming Institute of Botany, Academia Sinica, Kunming	-
	Northwest Teachers University, Lanzhou	-
	Jiangxi University, Nanchang	-
	East China Normal University, Shanghai	-
	Shanghai Museum of Natural History, Shanghai	-
	Institute of Applied Ecology, Academia Sinica, Shenyang	-
	August 1st Agricultural College, Urumqi	-
	Northwest University, Xian	-
	Northwestern Institute of Botany, Yangling	-
Philippines	University of the Philippines at Los Baños, Laguna	12 000
	National Museum, Manila	-
	University of the Philippines, Quezon City	-
Saudi Arabia		
Singapore	National University of Singapore, Singapore	100
Sri Lanka	National Herbarium, Peradeniya	-
Taiwan/Republic of China*	Tunghai University, Taichung	-
	Institute of Botany, Academia Sinica, Taipei	-
	National Taiwan University, Taipei	-
Thailand		
United Arab Emirates*		
Vietnam	College of Pharmacy, Hanoi	-
Yemen, Republic of		
Australasia and Pacific		
Australia*	Botanic Garden, Adelaide	-
	University of New England, Armidale	-
	Plant Research Institute, Burnley	16 000
	Australian National University, Canberra	30 000
	Australian National Botanic Gardens, Canberra	-
	Western Australian Herbarium, Como	-
	University of Tasmania, Hobart	-
	Dept. of Primary Industries, Indooroopilly	17 000
	Antarctic Division, Kingston	-
	Royal Botanic Gardens, Melbourne	-
	University of Melbourne, Melbourne	-
	Monash University, Melbourne	-
	CSIRO Division of Food Processing, North Ryde	100
	University of Western Australia, Perth	-
	Biological & Chemical Research Institute, Rydalmere	76 000
	Univ of Queensland, Saint Lucia	-
	Royal Botanic Gardens, Sydney	-

Annex 1 Dried reference collections of fungi (including lichens) within tropical countries

Location	Number of specimens (where known)
Forestry Commission of New South Wales, Sydney	-
Univ of New South Wales, Sydney	-
James Cook University of North Queensland, Townsville	-
Caroline Islands	
Cayman Islands	
Cook Islands	
Fiji	Univ of the South Pacific, Suva
French Polynesia	
Guam	
Hawaii	
Kiribati	
Macau	
Micronesia, Fed. States of	
Nauru	
New Caledonia	
Norfolk Island	
Papua New Guinea	Division of Primary Industry, Konedobu
	Forest Research Institute, Lae
	University of Papua New Guinea, Port Moresby
Pitcairn Island	
Solomon Islands	
Tokelau	
Tonga	
Tuvalu	
Vanuatu	
Wallis & Futuna	
Western Samoa	
Central America &	
West Indies	
Anguilla	
Antigua & Barbuda	
Aruba	
Bahamas, The	
Barbados	
Belize	
Bermuda	
Costa Rica	Universidad de Costa Rica, San José
Cuba	Instituto de Ecología y Sistemática, Habana
	Jardín Botánico Nacional, Habana
Dominica	
Dominican Republic	
El Salvador	
Grenada	
Guadeloupe	
Guatemala	
Haiti	
Honduras	
Jamaica	Institute of Jamaica, Kingston
Martinique	
Mexico	Universidad Autónoma de Aguascalientes, Aguascalientes

Annex 1 Dried reference collections of fungi (including lichens) within tropical countries

	Location	Number of specimens (where known)
	Instituto Tecnológico de Ciudad Victoria, Ciudad Victoria	-
	Universidad Autónoma de Baja California, Ensenada	-
	Centro de Investigación Científica de Yucatán, Mérida	-
	Instituto Politécnico Nacional, Mexico City	-
	(3) Universidad Nacional Autónoma de Mexico, Mexico City	-
	Universidad Autónoma Metropolitana-Iztapalapa, Mexico City	-
	Instituto de Ecología, Xalapa	-
	Universidad Veracruzana, Xalapa	-
	Universidad de Guadalajara, Zapopan	-
Montserrat		
Netherlands Antilles		
Nicaragua		
Panama	Universidad de Panama, Panama	-
Puerto Rico	University of Puerto Rico, Mayagüez	-
Saint Kitts & Nevis		
Saint Lucia		
Saint Vincent & The Grenadines		
Trinidad & Tobago	[National Herbarium of Trinidad & Tobago, St Augustine]	-
Virgin Islands		
South America		
Argentina	Instituto de Botanica C. Spegazzini, Buenos Aires	48 000
	Museo Argentino de Ciencias Naturales B. Rivadavia, Buenos Aires	-
	Universidad de Buenos Aires, Buenos Aires	-
	Instituto de Botánica del Nordeste, Corrientes	-
	Universidad Nacional de Salta, Salta	-
Bolivia		
Brazil*	Centro de Pesquisa Agropecuária do Trópico Umido, Belém	-
	Universidade Federal de Minas Gerais, Belo Horizonte	-
	Instituto Agronômico de Campinas, Campinas	8000
	Universidade Federal de Santa Catarina, Florianopolis	-
	Universidade Federal de Juiz de Fora, Juiz de Fora	-
	Instituto Nacional de Pesquisas da Amazônica, Manaus	-
	Fundação Zoobotânica do Rio Grande do Sul, Porto Alegre	-
	Universidade Federal do Rio Grande do Sul, Port Alegre	-
	Pontifícia Universidade Católica do Rio Grande do Sul, Porto Alegre	-
	Universidade Federal de Pernambuco, Recife	75 381
	Jardim Botânico do Rio de Janeiro, Rio de Janeiro	-
	Universidade Federal do Rio de Janeiro, Rio de Janeiro	-
	Instituto Biológico, Sao Paulo	17 123
	Instituto de Botânica, Sao Paulo	-
	Instituto Florestal, Sao Paulo	-
Chile*	Museo Nacional de Historia Natural, Santiago	-
	Universidad Austral de Chile, Valdivia	-
	Universidad de Playa Ancha, Valparaíso	-
Colombia	Instituto Colombiano Agropecuario, Bogotá	3500
Ecuador	Pontificia Universidad Católica del Ecuador, Quito	-
French Guiana	Institut Français de Recherche Scientifique, Cayenne	-
Guyana	University of Guyana, Georgetown	-
Paraguay*		

Annex 1 Dried reference collections of fungi (including lichens) within tropical countries

	Location	Number of specimens (where known)
Peru	Universidad Nacional San Antonio Abad del Cuzco, Cuzco	-
	Universidad Nacional de Trujillo, Trujillo	-
Suriname		
Venezuela	Jardín Botánico, Caracas	-
	Universidad de Oriente, Cumaná	-
	Centro Nacional de Investigaciones Agropecuarias, Maracay	6000
	Universidad de Los Andes, Mérida	-
	Universidad Nacional Experimental de los Llanos, Mesa de Cavaca	-

Notes: The names of countries mainly follow Daume (1991); * = countries the boundaries of which are not all located between the Tropics of Cancer and Capricorn (i.e. between latitudes 24°N and 24°S). Information in square brackets is derived from sources additional to those cited.
Sources: Buyck & Hennbert (1992), Hall & Hawksworth (1990), Holmgren *et al.* (1990) and CAB International staff.

Annex 2 Living reference collections of bacteria and fungi (including yeasts) within tropical countries

Location		Numbers of bacteria fungi (where known)	
Africa			
Algeria*			
Angola			
Benin			
Botswana			
Burkina Faso	Inst d'Etudes et de Res Agri, Centre de Res Agri du Sud, Bobo-Dioulasso	100	
	Centre Nat de la Rec Sci et Tech, Ouagadougou	35	
Burundi	Univ du Burundi, Lab de Microbiol, Bujumbara	600	
Cameroon	Centre Univ des Sci de la Santé, Lab de Mycol, Yaoundé	±30	
Cape Verde Islands			
Central African Republic			
Chad			
Comoros			
Congo	Office de la Rec Sci et Tech d'Outre-Mer, Lab de Phytopath, Brazzaville	in creation	
Côte d'Ivoire	Centre de Coop Intern en Rech, Dept du Caoutchouc, Adidjan	20	
	Inst de Rech du Café et du Cacao, Lab de Phytopath, Abidjan	50	
	IIRSDA, Lab de Phytopath, Adloposoumé, Abidjan	±30	
	Ecole Nat Supérieure Agron, Lab de Phytopath, Yamoussoukro	200	
Djibouti			
Egypt*	Cairo Microbiological Resource Centre, Cairo	50	210
	Univ of El Minia, El Minia		40
Equatorial Guinea			
Ethiopia			
Gabon			
Gambia			
Ghana	CSRI, Crops Res Inst, Kumasi	rudimentary	
Guinea	IRAG, Centre de rech agron de Foulaya, Guinée Maritime	17	
Guinea Bissau			
Kenya	University of Nairobi, Nairobi	205	-
Lesotho			
Liberia			
Libya*			
Madagascar	CENRADERU-FO.FI.FA., Dép de Rech Agron, Ambatobe		50
Malawi			
Mali*			
Mauritania*			
Mauritius	Univ of Mauritius, Dept of Natural Sci, Reduit		40
Mayotte			
Mozambique			
Namibia			
Niger			
Nigeria	International Institute of Tropical Agriculture, Ibadan	600	2
	Ogun State Univ, Ago-Iwoye		-
	State Univ of Teaching, Awka campus, Anambra State		32
	Univ of Benin, Ugbowo campus, Benin City		250
	Univ of Ibadan, Dept of Food Tech, Ibadan		rudimentary
	Univ of Jos, Bauchi Road campus, Jos		rudimentary
	Univ of Jos, Jos Plateau State, Med Microbiol & Mycol, Jos		90
	Univ of Nigeria, Lab of Mycol, Nsukka		220
	Fed Univ of Tech, Lake Nwaebere campus, Owerri		20
	Fed Univ of Tech, Biol Sci, Owerri		rudimentary

Annex 2 Living reference collections of bacteria and fungi (including yeasts) within tropical countries

Location		Numbers of bacteria fungi (where known)	
	Nigerian Stored Prod Res Inst, Dept of Microbiol, Port Harcourt	25	
	Ahmadu Bello Univ, Lab of Mycol, Zaria		rudimentary
Réunion	Lab Vétérinaire Dép Réunion, Sainte Clotilde	25	
Rwanda	ISAR, PNAP, Ruhengeri		very small
Saint Helena & Ascension			
Sao Tome & Principe			
Senegal	MIRCEN Afrique Ouest, Bambey	200	-
	ISRA, Lab of Phytopath, Dakar		100
	Univ Chelkh Anta Drop, Fac de Médecine et de Pharmacie, Dakar		120
Seychelles			
Sierra Leone			
Somalia			
South Africa*	Plant Protection Research Institute, Pretoria	500	3500
	CSFRI, Agric & Food Chem, Pretoria		5000
	PPRI, Plant Path, Pretoria		300
	South African Med Res Council, Lab of Mycol, Pretoria		in preparation
	VOPRI, Veg Plant Path, Pretoria		247
	Univ of Pretoria, Dept of Botany, Pretoria		300
	Inst of Medunsa, Dept of Dermtol, Medunsa		25
	CSFRI, Dept of Plant Path, Nelspruit		2500
	Outspan Citrus Centre, Nelspruit		15
	Univ of Natal, Lab of Virol & Plant Path, Pietermarizburg		very small
	Univ of Natal, Dept of Biol, Durban		300
	South African Med Res Council. Res Inst for Nutritional Disesaes, Tygerberg		7000
	Univ of Stellenbosch. Dept of Plant Path, Stellenbosch		500
	Red Cross Childrens Hospital, Lab of Microbiol, Rondebosch		150
	Univ of the Orange Free State, Lab of Tree Path & Mycol, Bloemfontein	150 plus	
	Univ of the Orange Free State, Dept of Plant Path, Bloemfontein		
Sudan, The	Agric Res Inst, Gezira Res Sta, Medani		40
Swaziland			
Tanzania	Uyole Agric Centre, Mbeya		80
Togo			
Uganda	Makerere Univ, Med School Lab, Kampala		±300
Zaire			
Zambia			
Zimbabwe	University of Zimbabwe, Harare.	130	30
	Soil Productivity Research Laboratory, Marondera	537	-
	Medical School Univ of Zimbabwe, Med Microbiol Dept, Harare		-
Asia			
Bangladesh*			
Brunei			
Cambodia			
Hong Kong	Chinese University of Hong Kong, Shatin	-	60
India*	Indian Institute of Science, Bangalore	214	121
	University of Bombay, Bombay	35	25
	Bose Institute, Calcutta	50	52
	University of Delhi, Delhi	-	200
	Indian Agricultural Research Institute, New Delhi	-	2500
	Vallabhbhai Patel Chest Institute, Delhi	-	?
	Indian Veterinary Research Institute, Izatnagar	100	3
	DRDO New Delhi, Kanpur	98	1175

Annex 2 Living reference collections of bacteria and fungi (including yeasts) within tropical countries

Location		Numbers of bacteria fungi (where known)	
Indonesia	Marathwada Agricultural University, Parbhani	4	3
	MACS Research Institute, Pune	246	11
	Mahatma Phule Agricultural University, Pune	10	13
	National Chemical Laboratory, Pune	1000	2000
	Institute of Technology, Bandung.	267	307
	Institut Pertanian Bogor, Bogor	ca.400	ca.300
	Research Institute for Veterinary Science, Bogor	644	38
	University of Indonesia, Depok	85	235
Laos			
Malaysia	National University of Malaysia, Bangi	228	68
	Universiti Kebangsaan Malaysia, Kuala Lumpur	370	32
	Universiti Pertanian Malaysia, Serdang	76	-
Maldives			
Myanmar/Burma			
Oman			
People's Republic of China*	Beijing Agricultural University, Beijing	400	-
	Institute of Food & Fermentation Industry, Beijing	330	1270
	Institute of Microbiology, Beijing	3000	6300
	Institute of Soils & Fertilizers, Beijing	850	1400
	Sichuan Industr. Institute of Antibiotics, Shanbangiao	574	51
	Huazhong Agricultural University, Shizishan	-	-
	Wuhan University, Wuhan	625	231
	National Institute of Biotechnology, Los Banos	532	358
Philippines	Museum of Natural History, Los Banos	234	315
	University of The Philippines, Los Banos	-	-
	Industr. Technology Dev. Institute, Manila	35	78
	University of The Philippines, Quezon City	148	445
Saudi Arabia*			
Singapore	Botany Dept., National University of Singapore, Singapore	90	456
	Microbiology Dept., National University of Singapore, Singapore	257	22
Sri Lanka	Rubber Research Institute, Colombo	-	5
	University of Kelaniya, Dalugama	82	20
	University of Jaffna, Jaffna	25	52
	Eastern University, Vantharumoolai	-	5
Taiwan/Republic of China*			
Thailand	Food Industr. Research & Dev. Institute, Hsinchu	1619	1559
	Dept. of Agriculture, Bangkok	60	7
	Faculty of Science, Bangkok	7	32
	Institute of Scientific Research, Bangkok	444	555
	Mahidol University, Bangkok	150	150
	Ministry of Science, Technology & Energy, Bangkok	-	16
	University of Hawaii NIFTAL Project, Bangkok	1000	-
	Prince of Songkla University, Haad-Yai	25	25
	Khon Kaen University, Khon Kaen	-	-
United Arab Emirates*			
Vietnam			
Yemen, Republic of			
Australasia and Pacific			
Australia*	Adelaide Children's Hospital, North Adelaide	-	2000
	SA Institute of Technology, Adelaide	2000	25

Annex 2 Living reference collections of bacteria and fungi (including yeasts) within tropical countries

Location		Numbers of bacteria fungi (where known)	
	WAITE Agricultural Research Institute, Adelaide	30	48
	Materials Research Laboratories, Ascot Vale	-	1200
	(2) Flinders University, Bedford Park	-	5500
	Forestry Commission (NSW), Beecroft	-	55
	CSIRO, Brisbane	1500	-
	Laboratory of Microbiology & Pathology, Brisbane	198	-
	Plant Research Institute, Burnley	-	650
	CSIRO, Canberra	1200	-
	CSIRO (Entomology), Canberra	16	250
	CSIRO (Soils), Glen Osmond	100	2000
	CSIRO, Highett	-	3203
	CSIRO (Starter Cultures), Highett	800	4
	Forestry Commission (Tasmania), Hobart	-	35
	University of Tasmania, Hobart	100	-
	Dept. of Primary Industries, Indooroopilly	-	700
	University of New South Wales, Kensington	560	125
	Tasmanian Dept. of Agriculture, Launceston	60	-
	Queen Elizabeth II Medical Centre, Nedlands	2500	100
	CSIRO, North Ryde	-	3100
	University of Melbourne, Parkville	460	31
	Victorian College of Pharmacy, Parkville	60	6
	CSR Central Laboratory, Pyrmont	90	260
	(2) Roseworthy Agricultural College, Roseworthy	41	126
	Department of Agriculture, Rydalmere	1500	2500
	W. Australian Dept. of Agriculture, South Perth	930	4041
	University of Queensland, St. Lucia	2600	227
	King Edward Memorial Hospital, Subiaco	1150	40
	Royal North Shore Hospital of Sydney, Sydney	98	923
	(2) University of Sydney, Sydney	3000	447
	Wheat Research Institute, Toowoomba	224	-
	James Cook University, Townsville	60	219
	Australian Wine Research Institute, Urrbrae	90	229
	Food Research Institute, Werribee	75	11
Caroline Islands			
Cayman Islands			
Cook Islands			
Fiji			
French Polynesia			
Guam			
Hawaii	MIRCEN & NIFTAL Project, University of Hawaii	1806	-
Kiribati			
Macau			
Micronesia, Fed. States of			
Nauru			
New Caledonia			
Norfolk Island			
Papua New Guinea	Department of Primary Industry, Port Moresby	270	-
Pitcairn Island			
Solomon Islands			
Tokelau			
Tonga			

Annex 2 Living reference collections of bacteria and fungi (including yeasts) within tropical countries

Location		Numbers of bacteria fungi (where known)	
Tuvalu			
Vanuatu			
Wallis & Futuna			
Western Samoa			
Central America & West Indies			
Anguilla			
Antigua & Barbuda			
Aruba			
Bahamas, The			
Barbados			
Belize			
Bermuda			
Costa Rica			
Cuba	[INIFAT, La Habana.	-	?)
Dominica			
Dominican Republic			
El Salvador			
Grenada			
Guadeloupe			
Guatemala	Instituto Centroamericano de Investigacion Industrial, Guatemala	74	182
Haiti			
Honduras			
Jamaica			
Martinique			
Mexico	CIAN-INIFAP-SARH, Coah	-	70
	Instituto Tecnologico de Durango, Durango	35	29
	Centro de Investigaciones Forestales, Mexico	-	1016
	Instituto de Salubridad y Enfermedades Tropicales, Mexico	334	484
	Instituto de Investigaciones Biomedicas, Mexico	150	80
	IPN (Biotecnologia y Bioingenieria), Mexico	280	690
	IPN (Ciencias Biologicas), Mexico	940	74
	Universidad Nacional Autonoma de Mexico, Mexico	180	80
Montserrat			
Netherlands Antilles			
Nicaragua			
Panama			
Puerto Rico	University of Puerto Rico, Mayaguez	400	1
Saint Kitts & Nevis			
Saint Lucia			
Saint Vincent & The Grenadines			
Trinidad & Tobago	Caribbean Industrial Res Inst, Tunapuna	-	-
Virgin Islands			
South America			
Argentina	Facultad Agronomis, Buenos Aires	1690	1205
	Facultad de Farmacia y Bioquimica, Buenos Aires	883	49
	Instituto de Botanica C. Spegazzini, Buenos Aires	-	200
	Instituto Nacional de Tecnologia Agropecuaria, Castelar	838	-

Annex 2 Living reference collections of bacteria and fungi (including yeasts) within tropical countries

Location		Numbers of bacteria fungi (where known)	
Bolivia	PROINT, Tucuman	20	500
Brazil*	Universidade Federal de Pernambuco (Antibioticos), Recife	379	199
	Universidade Federal de Pernambuco (Micologia), Recife	-	2012
	EMBRAPA, Rio de Janeiro	11	-
	Ministerio da Saude, Rio de Janeiro	157	110
	Instituto Oswaldo Cruz, Rio de Janeiro	600	-
	Instituto de Pesquisas Agronomicas, Rio Grande do Sul	1013	-
	Instituto Adolfo Lutz, Sao Paulo	2000	-
	Instituto Agronomico de Campinas, Sao Paulo	611	1200
	Instituto Biologico, Sao Paulo	600	-
	Instituto Zymotecnico, Sao Paulo	118	994
	Food Technology Institute, Sao Paulo	300	10
	FTPT, Sao Paulo	100	200
Chile*	Catholic University of Santiago, Santiago	160	14
Colombia	Centro Internacional de Agricultura Tropical, Cali	3961	-
Ecuador			
French Guiana			
Guyana			
Paraguay*			
Peru			
Suriname			
Venezuela	Universidad de Los Andes, Merida	150	-

Notes: The names of countries mainly follow Daume (1991); * = countries the boundaries of which are not all located between the Tropics of Cancer and Capricorn (i.e. between latitudes 24°N and 24°S).

Information in square brackets is derived from sources additional to those cited.

Sources: Buyck & Hennebert (1992), Hall & Hawksworth (1990), Takishima *et al.* (1989), and CAB International staff..

Annex 3 Preserved entomological reference collections within tropical countries

	Location	Number of specimens (where known)
Africa		
Algeria*	Centre National de Recherche sur les Zones Arides, Beni Abbes	-
Angola	?Museo Regional do Dundo, Luanda	-
Benin	?Open-air Museum of Ethnography & Natural Sciences, Parakou	-
Botswana	National Museum & Art Gallery, Gaborone	ca.1000
Burkina Faso		
Burundi		
Cameroon	?Douala Museum, Douala	
Cape Verde Islands		
Central African Republic		
Chad	?Chad National Museum, Fort Lamy	
Comoros		
Congo	?Musée National, Brazzaville	
Côte d'Ivoire	ORSTOM, Laboratoire d'Entomologie Agricole, Adiopodoumé	
Djibouti		
Egypt*	?Ain Shams University, Cairo	
	Faculty of Science, Cairo University, Cairo	70 000
	?El Azhar University, Cairo	
	Entomology Society of Egypt, Cairo	70 000
	Plant Protection Res Inst, Ministry of Agriculture, Cairo	100 000
Equatorial Guinea		
Ethiopia	?Haile Selassie I University, Addis Ababa	
	Institute of Agricultural Research	
Gabon		
Gambia		
Ghana	?University of Science & Technology, Kumasi	
Guinea	?Local Museum, N'Zerekore	
Guinea Bissau	?Museum of Portuguese Guinea Bissau	
Kenya	Coffee Research Foundation, Ruiru	
	Division of Vector-borne Diseases, Nairobi	
	Kenya Agricultural Research Institute, Nairobi	ca.42 000
	Kenya Forestry Research Institute, Muguga	
	National Museum of Kenya, Nairobi	ca.1 500 000
	?Wildlife Advisory & Research Service Ltd, Nairobi	
Lesotho		
Liberia		
Libya*	?Natural History Museum, Tripoli	
Madagascar	?Museum of Folklore, Archaeology & Palaeontology, Antananarivo	
Malawi	Museum of Malawi, Blantyre	ca.3000
	Bvumbwe Experiment Station, Limbe	ca.20 000
	Forest Research Institute, Zomba	ca.9000
	University of Malawi, Zomba	ca.18 000
	Makoka Research Station, Thondwe	
	Chitedze Research Station, Lilongwe	
Mali*		
Mauritania*		
Mauritius	?Mauritius Institute, Port Louis	
Mayotte		
Mozambique	?Dr Alvaro de Castro Provincial Museum, Lourenco Marques	
	[= Museum de Historia Natural, Maputo	ca.250 000]
Namibia	State Museum of Windhoek, Windhoek	ca.350 000

Annex 3 Preserved entomological reference collections within tropical countries

	Location	Number of specimens (where known)
	Desert Ecological Research Unit, Walvis Bay	
Niger		
Nigeria	University of Ibadan, Ibadan	
	Natural History Museum, University of Ife	
	Ahmadu Bello University, Zaria	
	Institute for Agricultural Research, Zaria	
Réunion	?Museum of Natural History, Saint-Denis	
Rwanda		
Saint Helena & Ascension		
Sao Tome & Principe		
Senegal	IFAN, Université de Dakar, Dakar	
Seychelles	National Archives & Museum Division, Mahe	> 600
Sierra Leone		
Somalia	Department of Plant Protection and Locust Control, Mogadishu	
	Agricultural University, Afgoi	
	Plant Quarantine Institute, Afgoi	
South Africa*	National Museum Bloemfontein, Bloemfontein	ca.89 000
	South African Museum, Cape Town	
	Durban Museum, Durban	ca.250 000
	?Albany Museum, Grahamstown	
	?Alexander McGregor Memorial Museum, Kimberley	
	South African Institute for Medical Research, Johannesburg	
	University of Natal, Pietermaritzburg	> 15 000
	Natal Museum, Pietermaritzburg	>100 000
	South African National Collection of Insects, Pretoria	ca. 5 000 000
	Transvaal Museum, Pretoria	>700 000
	University of Pretoria, Pretoria	ca.100 000
	?Queenstown & Frontier Museum, Queenstown	
Sudan, The	University of Khartoum, Khartoum	ca.1200
	National Insect Collection, Wad Medani	
	Plant Protection Department, Khartoum North	
Swaziland		
Tanzania	University of Dar es Salaam, Dar es Salaam	
	Serengeti Research Institute, Seronema	
	National Museum, Dar es Salaam	
Togo		
Uganda	?Kawanda Agricultural Research Station, Kampala	
	Ministry of Animal Industry & Fisheries, Kampala	ca.200 000
	Uganda Museum of Natural History, Kampala	ca.1000
Zaire	?Institut de Recherche Scientifique, Kinshasa/Gombe	
	Institut National des Etudes et de la Recherche Agronomique, Yougambi	
	Institut des Jardins Zoologiques et Botaniques de Kinshasa	
Zambia	Livingstone Museum, Livingstone	
	Mt. Makulu Research Station	4 400
Zimbabwe	National Museum of Natural History, Bulawayo	
	Plant Protection Research Institute, Harare	
	Mutare Museum, Mutare	

Annex 3 Preserved entomological reference collections within tropical countries

	Location	Number of specimens (where known)
Asia		
Bangladesh*	?University of Dacca, Dacca	
Brunei	[Department of Agriculture, Kota Baru] Brunei Museum, Kota Baru	
Cambodia		
Hong Kong	?Dept. of Agriculture & Fisheries, Kowloon	
India*	?St John's College, Agra	
	?Aligarh Muslini University, Aligarh	
	?Horticultural Research Station, Bangalore	
	University of Agricultural Sciences, Bangalore	30 000
	Bombay Natural History Society, Bombay	80 000
	?Calcutta University, Calcutta	
	National Zoological Collection, Zoological Survey of India, Calcutta	230 847
	?School of Tropical Medicine, Calcutta	
	?Punjab University, Chandigarh	
	?Tamil Nadu Agricultural University, Coimbatore	
	?Bengal Natural History Museum, Darjeeling	
	Indian Forest Research Institute, Dehra Dun	21 000
	?Malaria Research Centre, Delhi	
	Indian Agriculture Research Institute, New Delhi	ca.200 000
	National Museum of Natural History, New Delhi	>5000
	[University of Delhi]	150 000
	?Maharaja's College, Ernakulam	
	?Haryana Agricultural University, Hissar	
	?Kuruksheta University, Kuruksheta	
	?Punjab Agricultural University, Ludhiana	
	Loyola College, Madras	
	?Madras Christian College, Madras	
	Kerala Forest Research Institute, Peechi	>30 000
	?St Joseph's College, Tiruchirapalli	
Indonesia	?Zoological Museum, Bandung	
	Museum Zoologicum Bogoriense, Bogor	ca.30 000
Laos		
Malaysia	[Forest Research Institute of Malaysia, Kepong, Kuala Lumpur]	
	?National Museum, Kuala Lumpur	
	Sarawak Museum of Natural History, Kuching	ca.30 000
	[Asean Planti, Serdang]	
	[Department of Agriculture, Kuala Lumpur]	
	[Malaysian Agricultural Research and Development Institute, Serdang]	
	[University of malaya, Kuala Lumpur]	
	[Forest Research Centre, Sepilok, Sabah]	
	[Forest Research Centre, Kuching, Sarawak]	
	[Institute of Medical Research, Kuala Lumpur]	
	[Agricultural Research Centre, Tuaran, Sabah]	
	[Universiti Kebangsaan Malaysia, Bangi and Sabah]	
Maldives		
Myanmar/Burma	?Natural History Museum, Rangoon	
Oman	?Natural History Museum, Muscat	
People's Republic of China*	Academia Sinica, Beijing	2 000 000
	?Beijing Agricultural University, Beijing	
	?Beijing Natural History Museum, Beijing	
	?Academia Sinica, Guangzhou	

Annex 3 Preserved entomological reference collections within tropical countries

	Location	Number of specimens (where known)
	China Entomological Research Institute, Guangzhou	ca.170 000
	Research Institute of Entomology, Guangzhou	ca.260 000
	?University of Kunming, Kunming	
	?Academia Sinica, Shanghai	
	?Tianjin Museum of Natural History, Tianjin	
Philippines	?St Louis University Museum, Baguio City	
	Visayas State College of Agriculture, Baybay	
	University of San Carlos, Cebu City	> 50 000
	University of the Philippines, Laguna and Los Banos	
	International Rice Research Institute, Manila	
	?National Museum of the Philippines, Manila	
Saudi Arabia*		
Singapore	?Global Colosseum, Singapore	
	National Collection, University of Singapore	
Sri Lanka	?National Museum, Colombo	
Taiwan/Republic of China*	?Taiwan Provincial Government, Nan-Tou	
	?National Chung Hsing University, Taichung	
	?National Museum of Natural Science, Taichung	
	?Taiwan Agricultural Research Institute, Taichung	
	?Tunghai University, Taichung	
	?National Taiwan University, Taipei	
	?Taiwan Forestry Research Institute, Taipei	
	?Taiwan Provincial Museum, Taipei	
Thailand	[University of Chiangmai] Dept. of Agriculture, Bangkok	
United Arab Emirates*		
Vietnam	?Plant Protection Dept., Hanoi	
Yemen, Republic of		
Australasia and Pacific		
Australia*	Museum of Victoria, Abbotsford	
	South Australian Museum, Adelaide	
	?Queensland Museum, Brisbane	
	Australian National Insect Collection, CSIRO, Canberra City	
	University of Western Australia, Nedlands	
	Western Australian Museum, Perth	ca.103 500
	Biological & Chemical Research Institute, Rydalmere	ca.266 000
	University of Queensland, Saint Lucia	
	Macleay Museum, Sydney	> 500 000
	?Australian Museum, Sydney	
Caroline Islands		
Cook Islands	[Agriculture Department, Carotonga]	1 000
Fiji	?Koronivia Research Station, Nausori	ca.10 000
	The University of the South Pacific, Suva	ca.10 000
French Polynesia	?Papeete Museum, Rua Brea	
Guam	[University of Guam]	
Hawaii	Bernice P. Bishop Museum, Honolulu	
	Hawaii Dept. of Agriculture, Honolulu	> 150 000
	Hawaii Volcanoes National Park, Honolulu	ca.3500
	University of Hawaii, Honolulu	> 215 000

Annex 3 Preserved entomological reference collections within tropical countries

Location		Number of specimens (where known)
Kiribati	[Agriculture Department]	ca.2000
Macau		
Micronesia, Fed. States of		
Nauru		
New Caledonia	Office de la Recherche Scientifique et Technique Outre-mer, Noumea	
Norfolk Island		
Papua New Guinea	National Museum & Art Gallery, Boroko	ca.500
	Forest Research Centre, Bulolo	ca.45 000
	Dept. of Primary Industry, Konedobu	> 100 000
	?Papua New Guinea Public Museum, Port Moresby	
	University of Papua New Guinea, PO Box 320	ca.10 000
	Wau Ecology Institute, Wau	ca.15 000
Pitcairn Island		
Solomon Islands	?Ministry of Natural Resources, Honiara	
Tokelau		
Tonga	[Agriculture Department]	ca.1000
Tuvalu		
Vanuatu		
Wallis & Futuna		
Western Samoa	[Agriculture Department, Upolo]	ca.10 000
Central America & West Indies		
Anguilla		
Antigua & Barbuda		
Aruba		
Bahamas, The		
Barbados	Barbados Museum & Historical Society, St Ann's Garrison	20
	Caribbean Agricultural Research Institute, St Thomas	uncounted
Belize	National Insect Collection, Cayo District	950
Bermuda	Botanical Gardens, Hamilton	
Cayman Islands		
Costa Rica	Museo de Zoología, Ciudad Universitaria	> 800
	Museo de Insectos, Univ de Costa Rica	300 000
	[National Biodiversity Institute, Heredia	1 500 000]
	Museo Nacional de Costa Rica, San Jose	ca.10 000
Cuba	Academia de Ciencias de Cuba, Habana	800 00
	?Universidad de La Habana, La Habana	
	c/o Lic. G. Alayón G., San Antonio de los Baños	> 15 000
	c/o Mr H. Grillo R., Univ Central de las Villas	60 000
	c/o Lic. L.R. Hernández, Ciudad de la Habana	5 000
	Museo Nacional de Historia Natural, Ciudad de la Habana	40 000
	Univ Central de las Villas, Villa Clara	>4 000
	c/o Ing. F. de Zayas, El Vedado, Ciudad de la Habana	>44 000
Dominica		
Dominican Republic	Museo Nacional de Historia Natural, Santo Domingo	10 000
El Salvador	?Museo Nacional "David J. Guzman", San Salvador	
	?Natural History Museum, San Salvador	
	?Universidad de El Salvador, San Salvador	
Grenada		

Annex 3 Preserved entomological reference collections within tropical countries

	Location	Number of specimens (where known)
Guadeloupe	Institut National de la Recherche Agronomique de Guyane, Petit-Bourg	
	Institut de Recherches Entomologique de la Caribe, Pointe-a-Pitre	ca.80 000
Guatemala	?Museo Nacional de Historia Natural, Guatemala City	
	Universidad del Valle de Guatemala, Guatemala City	> 5000
Haiti		
Honduras	Escuela Nacional de Agricultura, Catacamas	ca.2000
	Ministerio de Recursos Naturales, Juticalpa	
	c/o R.D. Lehman, La Ceiba	> 3000
	c/o P.E. Jordan-Soto, San Pedro Sula	> 16 000
	Escuela Nacional de Ciencias Forstales, Siguatepeque	ca.60 000
Jamaica	Natural History Museum, Kingston	ca.22 000
	University of the West Indies, Kingston	uncounted
Martinique		
Mexico	Centro de Entomologica y Acarologia, Chapingo	> 20 000
	?Estacion Experimental de Agricolas de La Campara, Chihuahua	
	Instituto de Ecologia, Mexico	ca.120 000
	Instituto Nacional de Investigaciones Agricolas, Mexico	ca.85 000
	Museo de Historia Natural de la Ciudad de Mexico, Mexico	ca.80 000
	Universidad Nacional Autonoma de Mexico, Mexico	> 2 500 000
	Instituto Tecnologico de Monterrey, Monterrey	
	Centro de Investigaciones Agricolas Noroeste, Sonora	ca.9 600
	INIREB, Xalapa	
Montserrat		
Netherlands Antilles		
Nicaragua	?Colegio Central Americas, Managua	
	Centro Exp de Nueva Guinea, Zelaya	ca. 2 000
	CENAPROVE, Min Agric y Ganaderia, Managua	ca. 50 000
	SEA, Museo Entomologico, Leon	200 000
	Univ Nacional Agraria, Managua	4 000
	Univ Nacional Autonoma de Nicaragua Leon	< 15 000
	?Instituto Nacional de Tecnologia Agropecuaria, Managua	
Panama	c/o Dr H. Wolda, Balboa	
	Dr Graham B. Fairchild Museo de Invertebrados, Panama	> 44 000
	Smithsonian Tropical Res Inst, Balboa	uncounted
	Universidad de Panama, Panama	ca.15 000
	?Museo Nacional, Panama	
Puerto Rico	?University of Puerto Rico, Mayaguez	
Saint Kitts & Nevis		
Saint Lucia	WINBAN, Castries	small
Saint Vincent & The Grenadines		
Trinidad & Tobago	?Central Experiment Station, Centeno	
	IIBC, Curepe	ca.30 000
	?National Museum & Art Gallery, Port-of-Spain	
	University of the West Indies, St Augustine	
	CAREC, Port of Spain	uncounted
Virgin Islands		
South America		
Argentina	Museo Argentino de Ciencias Naturales, Buenos Aires	ca.800 000

Annex 3 Preserved entomological reference collections within tropical countries

	Location	Number of specimens (where known)
Bolivia	Universidad Nacional de La Plata, La Plata	>3 500 000
	Universidad Nacional de Cuyo, Mendoza	
	c/o A. Martinez, Salta	ca.44 000
	Instituto Investigaciones Entomologicas Salta, Salta	>50 000
	Instituto Patagonico de Ciencias Naturales, San Martin de los Andes	60 000
	Universidad Nacional de Tucuman, Tucuman	ca.2 800 000
	Museo Nacional de Historia Natural, La Paz	ca.3750
Brazil*	?Universidad Mayor de San Andres, La Paz	
	?Universidade Federal de Sergipe, Aracaju	
	?Instituto do Azucar e do Alcool, Araras	
	?EMBRAPA, Belem	
	?Instituto Evandro Chagas, Belem	
	Museu Paraense Emilio Goeldi, Belem	ca.500 000
	?Universidade Federal do Para, Belem	
	?Universidade Federal de Minas Gerais, Belo Horizonte	
	?Universidade Estadual de Sao Paulo, Botucatu	
	?Universidade de Brasilia, Brasilia	
	?Reserva Ecologica IBGE, Brasilia	
	?Instituto Agronomico de Campinas, Campinas	
	?Universidade Estadual de Campinas, Campinas	
	?EMBRAPA, Cruz das Almas	
	?Universidade Federal de Mato Grosso, Cuiaba	
	?Museu de Historia Natural Capao da Embuia, Curitiba	
	?Universidade Federal do Parana, Curitiba	
	?Universidade Federal Santa Catarina, Florianopolis	
	?Universidade Federal do Ceara, Fortaleza	
	?Centro de Pesquisas do Cacau, Itabuna	
	?Faculdade de Filosofia Ciencias e Letras, Itu	
	?Faculdade Ciencias Agraria e Veterinaria de Jaboticabal, Jaboticabal	
	?Universidade Federal da Paraiba, Joao Pessoa	
	?Escola Superior de Agricultura, Lavras	
	?EMBRAPA, Londrina	
	?Fundacao Universidade do Amazonas, Manaus	
	Instituto Nacional de Pesquisas da Amazonia, Manaus	ca.1 500 000
	?Fundacao Universidade Federal de Maringa, Maringa	
	?Escola Superior de Agricultura, Mossoro	
	?Universidade Federal do Rio Grande do Norte, Natal	
	?Universidade de Sao Paulo, Piracicaba	
	?EMBRAPA, Plantina	
	?Museu Anchieta, Porto Alegre	
	Museu de Ciencias Naturais, Porto Alegre	ca.57 000
	?Universidade de Sao Paulo, Ribeirao Preto	
	?Universidade Estadual de Sao Paulo, Rio Claro	
	?Pontificia Universidade Catolica do Rio Grande do Sul, Porto Alegre	
	?Universidade Federal do Rio Grande do Sul, Porto Alegre	
	c/o Dr S.A. Fragoso, Rio de Janeiro	20 000
	?Fundacao Instituto Oswaldo Cruz, Rio de Janeiro	
	?Museu Nacional, Rio de Janeiro	
	?Universidade Federal do Rio de Janeiro, Rio de Janeiro	
	?Universidade Santa Ursula, Rio de Janeiro	
	?Centro de Pesquisas Goncalo Muniz, Salvador	

Annex 3 Preserved entomological reference collections within tropical countries

	Location	Number of specimens (where known)
	?Universidade Federal de Santa Maria, Santa Maria	
	?Universidade Federal de Sao Carlos, Sao Carlos	
	?Museu de Zoologia, Sao Leopoldo	
	?Instituto Butanta, Sao Paulo	
	?Instituto de Pesquisas Tecnologicas, Sao Paulo	
	?Secretaria da Agricultura, Sao Paulo	
	Universidade de Sao Paulo, Sao Paulo	> 1 000 000
	?Universidade Federal de Viscosa, Viscosa	
Chile*	Universidade de Tarapaca, Arica	ca.60 000
	?Universidade de Concepcion, Concepcion	
	INIA Subestacion Experimental La Cruz, La Cruz	ca.50 000
	c/o Dr M. Cerda, Nunoa	35 000
	?Instituto de Estudios e Investigaciones Juan Ignacio Molina, Santiago	
	c/o L.G. Pena, Santiago	> 1 064 000
	Museo Nacional de Historia Natural, Santiago	ca.120 000
	c/o T.M. Rodriguez, Santiago	3000
	?Universidade de Chile, Santiago	
	c/o E. Krahmer, Valdivia	ca.3500
	Universidade Austral de Chile, Valdivia	ca.2500
	Universidade Catolica de Valparaiso, Valparaiso	ca.35 000
Colombia	c/o Dr I. Zenner-Polania, Bogota	ca.110 000
	?Museo de Ciencias Naturales "F. Carlos Lehmann", Cali	
	?Universidad Nacional de Caldas, Manizales	
	Facultad de Ciencias, Medellin	ca.100 000
	Universidad Nacional de Colombia, Palmira	ca.12 000
	?Universidad de Narino, Pasto	
	?Universidad del Cauca, Popayan	
Ecuador	?Charles Darwin Research Station, Galapagos	
	Universidad de Guayaquil, Guayaquil	> 25 000
	?Ecuadorian Institute of Natural Sciences, Quito	
	?Museo Ecuatoriano de Ciencias Naturales, Quito	
	Pontificia Universidad Catolica del Ecuador, Quito	ca.15 000
French Guiana	?Office de la Recherche Scientifique d'Outre-Mer, Cayenne	
Guyana	?Guyana Museum, Georgetown	
	?University of Guyana, Georgetown	
	NARI, East Coast Demerara	uncounted
Paraguay*	Servicio Forestal Nacional, Asuncion	
Peru	?Universidad Nacional de San Agustin, Arequipa	
	?Universidad Nacional San Antonio Abad, Cusco	
	?Universidad Nacional Agraria de la Selva, Huanuco	
	?Universidad Nacional de Trujillo, La Libertad	
	?Universidad Nacional "Pedro Ruiz Gallo", Lambayeque	
	?Estacion Experimental Agricola de la Molina, Lima	
	?Universidad Nacional Agraria, Lima	
	Universidad Nacional Mayor de San Marcos, Lima	ca.200 000
Suriname	Surinaams State Museum, Paramaribo	
	University of Surinam, Paramaribo	
	NZCS, Anton de Kom, Univ Paramaribo	12 000
Venezuela	Universidad Central de Venezuela, Aragua	
	?Universidad Centro Occidental, Lara	
	Universidad Centro Occidental, Cabudare	

Annex 3 Preserved entomological reference collections within tropical countries

Location	Number of specimens (where known)
?Universidad de los Andes, Merida	
?Universidad Nacional Experimental de los Llanos, Portuguesa	
Universidad del Zulia, Zulia	

Notes: The names of countries mainly follow Daume (1991); * = countries the boundaries of which are not all located between the Tropics of Cancer and Capricorn (i.e. between latitudes 24°N and 24°S). Information in square brackets is derived from sources additional to that cited. ? indicates collections which are presumed to exist even though information was not supplied to the source cited.

Sources: Arnett, & Samuelson, (1986), Ritchie (1987), Starr (1992), and CAB International and Natural Resources Institute staff.

Annex 4 Reference collections of plant nematodes and animal helminths within tropical countries

Location	Plant nematodes (where known)	Animal helminths
Africa		
Algeria*		
Angola		
Benin		
Botswana		
Burkina Faso		
Burundi		
Cameroon		
Cape Verde Islands		
Central African Republic		
Chad		
Comoros		
Congo		
Côte d'Ivoire		
Djibouti		
Egypt*	Ain Shams University, Cairo.	- Yes
Equatorial Guinea		
Ethiopia		
Gabon		
Gambia		
Ghana		
Guinea		
Guinea Bissau		
Kenya		
Lesotho		
Liberia		
Libya*		
Madagascar		
Malawi		
Mali*		
Mauritania*		
Mauritius		
Mayotte		
Mozambique		
Namibia		
Niger		
Nigeria		
Réunion		
Rwanda		
Saint Helena & Ascension		
Sao Tome & Principe		
Senegal	ORSTOM Laboratoire de Nématologie, Dakar.	Yes -
Seychelles		
Sierra Leone		
Somalia		
South Africa*	Rand Afrikaans University, Johannesburg.	Yes -
	Veterinary Research Institute, Onderstepoort.	- Yes
	Plant Protection Research Institute, Pretoria.	Yes -
Sudan, The		
Swaziland		
Tanzania		

Annex 4 Reference collections of plant nematodes and animal helminths within tropical countries

Location		Plant nematodes (where known)	Animal helminths
Togo			
Uganda			
Zaire			
Zambia			
Zimbabwe			
Asia			
Bangladesh*			
Brunei			
Cambodia			
Hong Kong			
India*	Zoological Survey of India, Calcutta.	Yes	Yes
	Indian Agricultural Research Institute, New Delhi.	Yes	-
Indonesia			
Laos			
Malaysia			
Maldives			
Myanmar/Burma			
Oman			
People's Republic of China*	Zhongshan Medical College, Guangzhou.	-	Yes
	University of the Philippines, Quezon City.	-	Yes
Philippines			
Saudi Arabia*			
Singapore			
Sri Lanka			
Taiwan/Republic of China*			
Thailand			
United Arab Emirates*			
Vietnam			
Yemen, Republic of			
Australasia and Pacific			
Australia*	South Australian Museum, Adelaide.	-	Yes
	Waite Agricultural Research Institute, Adelaide.	Yes	-
	Queensland Museum, Brisbane.	-	Yes
Caroline Islands			
Cayman Islands			
Cook Islands			
Fiji			
French Polynesia			
Guam			
Hawaii			
Kiribati			
Macau			
Micronesia, Fed. States of			
Nauru			
New Caledonia			
Norfolk Island			
Papua New Guinea			
Pitcairn Island			
Solomon Islands			

Annex 4 Reference collections of plant nematodes and animal helminths within tropical countries

Location	Plant nematodes (where known)	Animal helminths
Tokelau		
Tonga		
Tuvalu		
Vanuatu		
Wallis & Futuna		
Western Samoa		
Central America & West Indies		
Anguilla		
Antigua & Barbuda		
Aruba		
Bahamas, The		
Barbados		
Belize		
Bermuda		
Costa Rica		
Cuba		
Dominica		
Dominican Republic		
El Salvador		
Grenada		
Guadeloupe		
Guatemala		
Haiti		
Honduras		
Jamaica		
Martinique		
Mexico	Instituto de Biología, UNAM, Mexico.	- Yes
Montserrat		
Netherlands Antilles		
Nicaragua		
Panama		
Puerto Rico		
Saint Kitts & Nevis		
Saint Lucia		
Saint Vincent & The Grenadines		
Trinidad & Tobago		
Virgin Islands		
South America		
Argentina	Universidad Nacional de Córdoba, Córdoba.	Yes -
Bolivia		
Brazil*	Helminthological Collection of O. Cruz Institute, Rio de Janeiro.	- Yes
Chile*		
Colombia		
French Guiana		
Guyana		
Paraguay*		
Peru	International Potato Center, Lima.	Yes -

Annex 4 Reference collections of plant nematodes and animal helminths within tropical countries

Location	Plant nematodes (where known)	Animal helminths
Suriname		
Venezuela		

Notes: The names of countries mainly follow Daume (1991); * = countries the boundaries of which are not all located between the Tropics of Cancer and Capricorn (i.e. between latitudes 24°N and 24°S).

Sources: Lichtenfels & Pritchard (1982), and CAB International staff.

Annex 5 Synopsis of numbers of reference collections of microorganisms and invertebrates within tropical countries

	Live bacteria	Live fungi	Dead fungi	Dead insects	Dead plant nematodes	Dead animal helminths
Africa	7	51	43	75	3	2
Algeria*	-	-	-	1	-	-
Angola	-	-	-	1	-	-
Benin	-	-	-	1	-	-
Botswana	-	-	-	1	-	-
Burkina Faso	-	2	-	-	-	-
Burundi	-	1	1	-	-	-
Cameroon	-	1	-	1	-	-
Cape Verde Islands	-	-	-	-	-	-
Central African Republic	-	-	-	-	-	-
Chad	-	-	-	1	-	-
Comoros	-	-	-	-	-	-
Congo	-	1	1	1	-	-
Côte d'Ivoire	-	4	1	1	-	-
Djibouti	-	-	-	-	-	-
Egypt*	1	2	1	5	-	1
Equatorial Guinea	-	-	-	-	-	-
Ethiopia	-	-	1	2	-	-
Gabon	-	-	-	-	-	-
Gambia	-	-	-	-	-	-
Ghana	-	1	3	1	-	-
Guinea	-	1	1	1	-	-
Guinea Bissau	-	-	-	1	-	-
Kenya	1	-	4	6	-	-
Lesotho	-	-	-	-	-	-
Liberia	-	-	-	-	-	-
Libya*	-	-	-	1	-	-
Madagascar	-	1	2	1	-	-
Malawi	-	-	-	6	-	-
Mali*	-	-	-	-	-	-
Mauritania*	-	-	-	-	-	-
Mauritius	-	1	1	1	-	-
Mayotte	-	-	-	-	-	-
Mozambique	-	-	-	1	-	-
Namibia	-	-	-	2	-	-
Niger	-	-	-	-	-	-
Nigeria	1	12	9	4	-	-
Réunion	-	1	-	1	-	-
Rwanda	-	1	1	-	-	-
Saint Helena & Ascension	-	-	-	-	-	-
Sao Tome & Principe	-	-	-	-	-	-
Senegal	1	2	1	1	1	-
Seychelles	-	-	-	1	-	-
Sierra Leone	-	-	1	-	-	-
Somalia	-	-	-	3	-	-
South Africa*	1	16	10	12	2	1
Sudan, The	-	1	-	3	-	-
Swaziland	-	-	-	-	-	-

Annex 5 Synopsis of numbers of reference collections of microorganisms and invertebrates within tropical countries

	Live bacteria	Live fungi	Dead fungi	Dead insects	Dead plant nematodes	Dead animal helminths
Tanzania	-	1	-	3	-	-
Togo	-	-	-	-	-	-
Uganda	-	1	1	3	-	-
Zaire	-	-	1	3	-	-
Zambia	-	-	-	2	-	-
Zimbabwe	2	1	3	3	-	-
Asia	46	47	40	68	2	3
Bangladesh*	-	-	-	1	-	-
Brunei	-	-	-	1	-	-
Cambodia	-	-	-	-	-	-
Hong Kong	-	1	-	1	-	-
India*	12	12	12	23	2	1
Indonesia	4	4	1	2	-	-
Laos	-	-	-	-	-	-
Malaysia	3	3	2	4	-	-
Maldives	-	-	-	-	-	-
Myanmar/Burma	-	-	-	1	-	-
Oman	-	-	1	1	-	-
People's Republic of China*	7	7	15	9	-	1
Philippines	5	3	6	6	1	-
Saudi Arabia*	-	-	-	-	-	-
Singapore	2	2	1	2	-	-
Sri Lanka	4	4	1	1	-	-
Taiwan/Republic of China*	1	1	3	8	-	-
Thailand	8	8	-	1	-	-
United Arab Emirates*	-	-	-	-	-	-
Vietnam	-	-	1	1	-	-
Yemen, Republic of	-	-	-	-	-	-
Australasia and Pacific	37	37	24	25	1	2
Australia*	35	35	20	10	1	2
Caroline Islands	-	-	-	-	-	-
Cayman Islands	-	-	-	-	-	-
Cook Islands	-	-	-	-	-	-
Fiji	-	-	1	2	-	-
French Polynesia	-	-	-	1	-	-
Guam	-	-	-	-	-	-
Hawaii	1	1	-	4	-	-
Kiribati	-	-	-	-	-	-
Macau	-	-	-	-	-	-
Micronesia, Fed. States of	-	-	-	-	-	-
Nauru	-	-	-	-	-	-
New Caledonia	-	-	-	1	-	-
Norfolk Island	-	-	-	-	-	-
Papua New Guinea	1	1	3	6	-	-
Pitcairn Island	-	-	-	-	-	-
Solomon Islands	-	-	-	1	-	-
Tokelau	-	-	-	-	-	-

Annex 5 Synopsis of numbers of reference collections of microorganisms and invertebrates within tropical countries

	Live bacteria	Live fungi	Dead fungi	Dead insects	Dead plant nematodes	Dead animal helminths
Tonga	-	-	-	-	-	-
Tuvalu	-	-	-	-	-	-
Vanuatu	-	-	-	-	-	-
Wallis & Futuna	-	-	-	-	-	-
Western Samoa	-	-	-	-	-	-
Central America & West Indies	12	12	17	58	-	1
Anguilla	-	-	-	-	-	-
Antigua & Barbuda	-	-	-	-	-	-
Aruba	-	-	-	-	-	-
Bahamas, The	-	-	-	-	-	-
Barbados	-	-	-	2	-	-
Belize	-	-	-	-	-	-
Bermuda	-	-	-	1	-	-
Costa Rica	-	-	1	4	-	-
Cuba	1	1	2	8	-	-
Dominica	-	-	-	-	-	-
Dominican Republic	-	-	-	1	-	-
El Salvador	-	-	-	3	-	-
Grenada	-	-	-	-	-	-
Guadeloupe	-	-	-	2	-	-
Guatemala	1	1	-	2	-	-
Haiti	-	-	-	-	-	-
Honduras	-	-	-	5	-	-
Jamaica	-	-	1	2	-	-
Martinique	-	-	-	-	-	-
Mexico	8	8	10	9	-	1
Montserrat	-	-	-	-	-	-
Netherlands Antilles	-	-	-	-	-	-
Nicaragua	-	-	-	7	-	-
Panama	-	-	1	5	-	-
Puerto Rico	1	1	1	1	-	-
Saint Kitts & Nevis	-	-	-	-	-	-
Saint Lucia	-	-	-	1	-	-
Saint Vincent & The Grenadines	-	-	-	-	-	-
Trinidad & Tobago	1	1	[1]	5	-	-
Virgin Islands	-	-	-	-	-	-
South America	20	19	34	106	2	1
Argentina	5	5	5	7	1	-
Bolivia	-	-	-	2	-	-
Brazil*	12	12	15	51	-	1
Chile*	1	1	3	12	-	-
Colombia	1	1	1	7	-	-
Ecuador	-	-	1	5	-	-
French Guiana	-	-	1	1	-	-
Guyana	-	-	1	3	-	-
Paraguay*	-	-	-	1	-	-

**Annex 5 Synopsis of numbers of reference collections of microorganisms and invertebrates
within tropical countries**

	Live bacteria	Live fungi	Dead fungi	Dead insects	Dead plant nematodes	Dead animal helminths
Peru	-	-	2	8	1	-
Suriname	-	-	-	3	-	-
Venezuela	1	1	5	6	-	-

Notes: The names of countries mainly follow Daume (1991); * countries the boundaries of which are not all located between the Tropics of Cancer and Capricorn (i.e. between latitudes 24°N and 24°S).

Annex 6 Numbers of helminth and nematode identifications by the International Institute of Parasitology (CABI) 1983-91

Number of Animal Helminth Taxonomy Identifications for member countries of
CAB International for each year from 1 April - 31 March

Member Countries	83-84	84-85	85-86	86-87	87-88	88-89	89-90	1991
Australia	142	87	117	83	10	-	-	-
Bangladesh	-	7	-	-	-	-	-	-
Botswana	-	-	-	-	-	-	-	-
Brunei	-	-	-	-	-	-	-	-
Canada	-	-	-	3	-	19	14	-
Cyprus	-	-	-	-	-	-	-	-
Dominica	-	-	-	-	-	-	-	-
Falkland Islands	8	-	-	-	-	-	-	-
Fiji	-	-	-	-	-	-	-	6
Gabon	-	-	-	-	-	-	-	-
Gambia	-	-	-	-	-	46	13	34
Gibraltar	-	-	-	-	-	-	-	-
Ghana	-	-	-	-	-	-	-	-
Guyana	-	-	-	5	2	-	1	3
Hong Kong	-	-	-	-	-	-	-	-
India	5	-	7	2	3	2	1	-
Jamaica	-	18	-	-	-	-	-	-
Kenya	539	76	12	115	225	-	-	-
Malawi	-	-	2	-	2	-	-	-
Malaysia	114	27	41	23	-	1	1	4
Mauritius	-	-	-	-	-	-	-	-
New Zealand	-	1	-	1	-	3	3	-
Nigeria	31	42	57	8	21	7	3	45
Papua New Guinea	-	-	-	-	-	-	-	-
Sierra Leone	-	-	5	-	-	2	-	-
Solomon Islands	-	-	-	-	-	-	-	-
Sri Lanka	4	-	-	-	9	-	-	-
Tanzania	30	139	38	-	-	60	15	2
Trinidad & Tobago	-	-	6	15	-	8	-	-
Tuvalu	-	-	-	-	-	-	-	-
Uganda	-	-	-	-	-	-	-	-
United Kingdom	153	244	471	412	444	341	401	107
Vanuatu	-	-	-	-	-	-	-	-
Zambia	-	7	3	-	1	-	-	-
Zimbabwe	9	72	39	182	21	81	47	2
Sub-total:	1035	720	789	848	738	590	499	203

Annex 6 Numbers of helminth and nematode identifications by the International Institute of Parasitology (CABI) 1983-91

Number of Animal Helminth Taxonomy Identifications for member countries of
CAB International for each year from 1 April - 31 March

Non-Member Countries	83-84	84-85	85-86	86-87	87-88	88-89	89-90	1991
Afghanistan	2	-	13	7	-	-	-	-
Argentina	-	-	-	-	1	-	-	-
Bhutan	-	-	-	-	-	-	-	-
Brazil	-	-	-	-	-	-	-	-
Burundi	-	-	-	-	-	-	-	-
Chile	-	-	-	-	1	1	-	-
China	-	-	-	-	-	-	-	-
Colombia	-	-	-	-	-	-	-	-
Denmark	-	-	-	-	-	-	-	1
Egypt	4	-	-	5	-	-	-	2
Eire	-	3	-	-	-	-	1	15
Eritrea	-	-	-	-	-	-	-	-
Ethiopia	-	-	-	9	-	-	-	-
France	-	-	-	23	-	-	-	-
Germany	-	9	4	4	4	-	-	-
Iceland	-	-	-	-	-	-	-	2
Indonesia	-	-	-	-	-	-	-	-
Iraq	-	11	1	47	-	-	-	-
Italy	-	-	-	-	1	-	1	-
Kuwait	-	-	-	-	-	-	110	-
Netherlands	-	-	5	-	-	2	-	-
Niger (ICRISAT)	-	-	-	-	-	-	-	-
Norway	11	5	17	4	-	150	71	2
Oman	-	-	-	-	-	-	-	-
Pakistan	2	-	2	-	-	-	-	-
Panama	-	-	-	-	-	-	-	-
Philippines	-	3	-	-	-	-	-	-
Saudi Arabia	-	-	-	1	1	-	-	-
Senegal	-	-	-	-	-	-	-	-
Somalia	-	-	-	-	-	-	-	-
Spain	-	-	-	-	-	12	14	-
Sudan	2	6	1	3	-	-	-	-
Sweden	2	1	-	2	3	-	4	-
Switzerland	-	78	-	-	-	-	-	-
Thailand	-	-	-	-	-	1	10	-
Turkey	-	12	-	-	-	-	-	-
USA	-	-	-	-	-	-	-	2
Zaire	-	-	-	20	367	-	-	-
Sub-total:	23	126	43	126	377	166	211	24
Total all countries:	1058	846	841	974	1115	756	710	227

Annex 6 International Institute of Parasitology Identification 1983 - 91

Number of Plant (and insect) Parasitic Nematode Identifications for member countries of CAB International for each year from 1 April - 31 March

Member Countries	83-84	84-85	85-86	86-87	87-88	88-89	89-90	1991
Australia	164	2	12	47	28	7	19	4
Bangladesh	-	15	-	1	-	26	-	-
Botswana	-	-	-	-	7	13	-	-
Barbados	-	-	-	-	-	-	5	1
Belize	-	-	-	-	-	-	-	6
Canada	-	-	-	-	-	71	-	-
Cyprus	3	-	1	7	1	17	59	-
Dominica	16	-	-	11	-	-	-	-
Falkland Islands	-	-	-	-	-	-	-	-
Fiji	-	-	-	13	-	6	-	21
Gabon	2	-	-	-	-	-	-	-
Gambia	-	-	-	-	-	-	-	-
Gibraltar	3	-	-	-	-	-	-	-
Ghana	-	-	-	9	-	-	1	-
Guyana	-	-	-	-	-	-	-	-
Hong Kong	91	-	-	-	-	11	56	14
India	133	325	155	97	213	147	25	148
Jamaica	-	-	-	-	-	-	-	-
Kenya	1	-	4	-	-	1	-	-
Malawi	-	37	59	-	1	-	-	171
Malaysia	-	32	18	8	36	26	70	4
Mauritius	1	7	3	-	-	2	2	-
New Zealand	-	-	-	-	-	-	-	-
Nigeria	22	2	-	-	-	99	-	26
Papua New Guinea	686	110	13	215	8	33	-	2
Sierra Leone	-	-	-	23	-	22	-	380
Solomon Islands	-	-	74	-	-	-	4	-
Sri Lanka	-	1	1	1	1	13	30	28
Tanzania	85	279	47	29	1	2	13	19
Trinidad & Tobago	-	9	4	13	-	52	109	-
Tuvalu	-	-	24	-	-	-	-	-
Uganda	-	-	-	-	-	-	-	76
United Kingdom	79	112	79	38	29	39	23	849
Vanuatu	1	-	15	-	-	-	-	-
Zambia	-	-	-	-	3	-	-	-
Zimbabwe	-	-	214	193	-	200	-	-
Sub-total:	1287	933	723	705	332	787	416	1848

Annex 6 International Institute of Parasitology Identification 1983 - 91

Number of Plant (and insect) Parasitic Nematode Identifications for member countries of CAB International for each year from 1 April - 31 March

Nou-Member Countries	83-84	84-85	85-86	86-87	87-88	88-89	89-90	1991
Afghanistan	167	315	592	214	-	-	-	-
Argentina	-	-	-	-	-	-	-	-
Bhutan	-	1	8	-	10	-	-	-
Brazil	-	125	111	11	-	-	-	-
Burundi	-	-	-	-	14	-	-	-
Cameroon	-	-	-	-	-	-	264	-
China	-	-	-	-	-	2	-	-
Cocos Islands	-	-	-	-	-	-	-	3
Colombia	-	-	-	884	-	2	2	-
Egypt	-	-	-	-	29	-	-	-
Eire	-	-	-	-	-	-	-	-
Eritrea	-	-	-	-	-	5	-	-
Ethiopia	-	-	-	58	-	5	3	-
France	-	-	-	-	-	-	-	1
Germany	-	-	-	-	-	1	-	-
Greece	-	-	-	-	-	-	-	6
Indonesia	33	-	-	-	-	-	182	1
Iraq	-	-	-	-	-	-	-	-
Italy	-	-	-	-	-	-	2	22
Ivory Coast	-	-	-	-	-	-	-	115
Mozambique	-	-	-	35	-	-	-	-
Mali	-	-	-	-	-	-	-	14
Martinique	-	-	-	-	-	-	-	6
Nepal	-	-	-	-	-	-	-	2
Netherlands	-	-	-	-	-	-	-	-
Niger (ICRISAT)	-	-	-	-	-	47	-	-
Oman	-	-	-	-	8	-	-	-
Portugal	-	-	-	-	-	-	2	-
Pakistan	-	-	-	-	2	-	12	25
Panama	-	-	7	1	-	-	-	-
Philippines	15	71	67	-	179	-	-	-
Saudi Arabia	-	7	3	16	-	-	-	-
Senegal	-	-	6	-	-	-	-	-
Somalia	-	-	-	-	-	22	-	-
Spain	-	-	-	1	11	2	-	7
Sudan	-	-	-	-	-	-	-	-
Sweden	-	-	-	-	-	-	-	-
Switzerland	-	2	1	-	-	-	-	-
Thailand	-	-	2	-	4	-	-	-
Turkey	-	-	-	-	-	49	-	-
Zaire	-	-	-	-	-	-	-	-
Sub-total:	235	521	791	1220	279	135	467	202
Total all countries:1522	1454	1514	1925	611	922	883	2050	
Grand Total (Helminths + Plant Nematodes):	2580	2300	2355	2899	1726	1678	1593	3246

Annex 7 Indicators of the resource base for mycological investigations within tropical countries (adapted from Hawksworth, 1993a)

Country	New fungi described 1981/90 ¹	Human resources			Information resources					
		National Societies ²	BMS ³	MSA ⁴	IAL ⁵	BLS ⁶	Plant ⁷ Diseases	Lichens ⁸	Macro- mycetes ⁹	Micro- mycetes ¹⁰
Africa	1226	-	33	20	15	1	-	-	-	-
Algeria*	22	-	1	-	1	-	2	1	1	1
Angola	4	-	-	-	-	-	-	1	1	1
Benin	-	-	-	-	-	-	-	-	1	1
Botswana	1	-	-	-	-	-	-	-	1	1
Burkina Faso	1	-	-	1	-	-	-	-	1	1
Burundi	30	-	-	-	-	-	-	-	-	-
Cameroon	56	-	-	-	-	-	2	2	-	-
Cape Verde Islands	-	-	-	-	-	-	-	-	1	-
Central African Republic	94	-	-	-	-	-	-	2	-	-
Chad	1	-	-	-	-	-	-	-	3	-
Comoros	-	-	-	-	-	-	-	1	1	-
Congo	11	-	-	-	-	-	-	1	-	-
Côte d'Ivoire	43	-	-	-	-	-	2	-	3	1
Djibouti	-	-	-	-	-	-	1	1	1	1
Egypt*	17	-	8	3	-	-	-	-	-	-
Equatorial Guinea	1	-	-	-	-	-	2	1	1	1
Ethiopia	23	-	1	-	1	-	-	-	-	-
Gabon	39	-	-	-	-	-	2	1	-	2
Gambia	-	-	-	-	-	-	1	-	-	-
Ghana	21	-	-	-	-	-	-	-	-	-
Guinea	-	-	-	-	-	-	2	-	1	2
Guinea Bissau	-	-	-	-	-	-	-	1	-	1
Kenya	79	-	-	-	-	-	-	-	-	-
Lesotho	17	-	-	-	-	-	2	3	3	1
Liberia	6	-	-	-	-	-	-	-	-	-
Libya*	5	-	-	1	-	-	-	-	-	-
Madagascar	14	-	1	-	-	-	1	1	-	-
Malawi	14	-	-	-	-	-	2	1	3	-
		-	-	-	-	-	2	-	3	-

Annex 7 Indicators of the resource base for mycological investigations within tropical countries (adapted from Hawksworth, 1993a)

Country	New fungi described 1981/90 ¹	Human resources				Information resources				
		National Societies ²	BMS ³	MSA ⁴	IAL ⁵	BLS ⁶	Plant ⁷ Diseases	Lichens ⁸	Macro- mycetes ⁹	Micro- mycetes ¹⁰
Mali*	-	-	-	-	-	-	-	-	-	-
Mauritania*	7	-	-	-	-	-	-	1	-	-
Mauritius	8	-	1	-	-	-	2	1	1	1
Mayotte	-	-	-	-	-	-	-	-	-	-
Mozambique	3	-	-	-	-	-	2	1	-	-
Namibia	43	-	-	-	-	-	-	1	-	-
Niger	-	-	-	-	-	-	1	1	-	-
Nigeria	21	-	3	6	-	1	2	1	1	1
Réunion	27	-	-	-	-	-	1	1	-	-
Rwanda	7	-	-	-	-	-	2	2	1	-
Saint Helena & Ascension	-	-	-	-	-	-	-	-	-	-
Sao Tome & Principe	-	-	-	-	-	-	1	1	-	-
Senegal	6	-	-	-	-	-	2	-	-	-
Seychelles	-	-	-	-	-	-	1	-	-	-
Sierra Leone	26	-	1	1	-	-	2	2	1	2
Somalia	2	-	-	-	-	-	2	1	-	-
South Africa*	282	-	14	7	13	-	3	2	3	3
Sudan, The	8	-	1	1	-	-	2	-	-	1
Swaziland	2	-	-	-	-	-	-	-	-	-
Tanzania	72	-	-	-	-	-	2	3	3	-
Togo	1	-	-	-	-	-	1	-	-	1
Uganda	31	-	-	-	-	-	1	3	3	2
Zaire	112	-	-	-	-	-	2	2	1	1
Zambia	19	-	-	-	-	-	2	1	1	-
Zimbabwe	13	-	2	-	-	-	2	1	1	1
Asia	3523	-	74	72	15	3	-	-	-	-
Bangladesh*	2	-	-	-	-	-	1	2	-	1
Brunei	24	-	-	-	-	-	2	-	1	-

Annex 7 Indicators of the resource base for mycological investigations within tropical countries (adapted from Hawksworth, 1993a)

Country	New fungi described 1981/90 ¹	Human resources			Information resources					
		National Societies ²	BMS ³	MSA ⁴	IAL ⁵	BLS ⁶	Plant Diseases ⁷	Lichens ⁸	Macro- mycetes ⁹	Micro- mycetes ¹⁰
Cambodia	-	-	-	-	-	-	2	-	-	-
Hong Kong	6	-	4	2	-	-	2	3	1	-
India*	1554	200	38	27	8	3	3	3	2	3
Indonesia	67	-	3	5	-	-	2	1	1	1
Laos	1	-	-	-	-	-	1	-	-	-
Malaysia	432	-	5	-	-	-	3	1	1	1
Maldives	-	-	-	-	-	-	-	-	-	1
Myanmar (Burma)	-	-	-	-	-	-	-	-	-	-
Oman	2	-	2	-	-	-	-	-	-	-
People's Republic of China*	919	-	4	5	5	-	1	1	1	3
Philippines	33	-	1	5	1	-	2	3	1	3
Saudi Arabia*	2	-	5	4	-	-	2	2	2	2
Singapore	82	-	4	2	-	-	1	2	-	-
Sri Lanka	107	-	1	-	-	-	1	1	-	-
Taiwan* (Republic of China)	260	225	5	21	1	1	2	3	3	2
Thailand	31	-	1	1	-	-	3	3	1	2
United Arab Emirates*	-	-	1	-	-	-	2	1	1	-
Vietnam	-	-	-	-	-	-	-	-	-	-
Yemen, Republic of	1	-	-	-	-	-	2	1	-	-
		-	-	-	-	-	2	1	-	-
Australasia and Pacific	947	-	74	11	9	11	-	-	-	-
Australia*	634	-	72	11	9	10	2	3	2	2
Caroline Islands	16	-	-	-	-	-	-	-	-	-
Cayman Islands	1	-	-	-	-	-	-	-	-	-
Cook Islands	2	-	-	-	-	-	-	-	-	-
Fiji	4	-	-	-	-	-	2	1	1	-
French Polynesia	-	-	-	-	-	-	1	1	-	-
Guam	4	-	-	-	-	-	-	-	-	-
Hawaii	10	-	-	-	-	1	2	2	-	1

Annex 7 Indicators of the resource base for mycological investigations within tropical countries (adapted from Hawksworth, 1993a)

Country	New fungi described 1981/90 ¹	Human resources			Information resources					
		National Societies ²	BMS ³	MSA ⁴	IAL ⁵	BLS ⁶	Plant ⁷ Diseases	Lichens ⁸	Macro- mycetes ⁹	Micro- mycetes ¹⁰
Kiribati	-	-	-	-	-	-	-	-	-	-
Macau	-	-	-	-	-	-	-	-	-	-
Micronesia, Fed. States of	-	-	-	-	-	-	-	1	1	-
Nauru	-	-	-	-	-	-	-	-	-	-
New Caledonia	18	-	-	-	-	-	1	1	1	1
Norfolk Island	2	-	-	-	-	-	-	-	1	1
Papua New Guinea	174	-	2	-	-	-	2	2	2	2
Pitcairn Island	2	-	-	-	-	-	-	-	-	-
Solomon Islands	75	-	-	-	-	-	2	1	2	2
Tokelau	-	-	-	-	-	-	-	-	-	-
Tonga	1	-	-	-	-	-	2	-	-	-
Tuvalu	-	-	-	-	-	-	-	-	-	-
Vanuatu	-	-	-	-	-	-	2	-	1	-
Wallis & Futuna	-	-	-	-	-	-	-	-	-	-
Western Samoa	3	-	-	-	-	-	2	-	-	-
Central America & West Indies										
Anguilla	811	-	14	30	2	1	-	-	-	-
Antigua & Barbuda	1	-	-	-	-	-	-	-	-	-
Aruba	-	-	-	-	-	-	-	-	-	-
Bahamas, The	-	-	-	-	-	-	-	2	-	-
Barbados	-	1	-	-	-	-	2	-	-	-
Belize	23	-	-	-	-	-	1	1	-	-
Bermuda	5	-	-	-	-	-	2	1	-	-
Costa Rica	89	4	2	1	-	-	-	1	1	1
Cuba	291	99	-	-	-	-	2	3	3	2
Dominica	5	-	-	-	-	-	2	3	3	-
Dominican Republic	5	-	1	1	-	-	2	1	2	2
El Salvador	-	14	1	1	-	-	2	1	-	-

Annex 7 Indicators of the resource base for mycological investigations within tropical countries (adapted from Hawksworth, 1993a)

Country	New fungi described 1981/90 ¹	Human resources				Information resources				
		National Societies ²	BMS ³	MSA ⁴	IAL ⁵	BLS ⁶	Plant ⁷ Diseases	Lichens ⁸	Macro- mycetes ⁹	Micro- mycetes ¹⁰
Grenada	2	-	-	-	-	-	-	-	1	-
Guadeloupe	23	-	-	-	-	-	-	2	3	-
Guatemala	12	4	-	-	-	-	1	1	-	-
Haiti	-	-	-	-	-	-	2	1	-	2
Honduras	12	-	1	-	-	-	-	1	-	-
Jamaica	29	-	-	-	-	-	2	2	2	-
Martinique	59	-	-	-	-	-	-	-	3	-
Mexico	165	201	5	11	2	1	2	3	3	-
Montserrat	1	-	-	-	-	-	-	-	-	-
Netherlands Antilles	1	-	-	-	-	-	-	-	-	-
Nicaragua	5	-	-	-	-	-	1	-	-	-
Panama	29	1	-	-	-	-	2	1	1	-
Puerto Rico	27	1	1	16	-	-	2	2	2	2
Saint Kitts & Nevis	-	-	-	-	-	-	-	-	-	-
Saint Lucia	2	-	1	-	-	-	-	-	-	-
Saint Vincent & The Grenadines	1	-	-	-	-	-	2	-	-	-
Trinidad & Tobago	8	-	1	-	-	-	2	2	2	-
Virgin Islands	7	-	-	-	-	-	2	1	2	-
South America	1369	-	19	14	6	7	-	-	-	-
Argentina	256	189	7	3	1	4	2	3	3	2
Bolivia	21	-	-	-	-	-	1	1	-	-
Brazil*	569	297	4	6	4	2	3	3	3	2
Chile*	152	12	2	2	-	-	2	3	1	2
Colombia	101	37	1	2	-	-	2	1	1	-
Ecuador	50	-	1	-	-	-	1	1	1	-
French Guiana	24	-	-	-	-	-	-	2	2	-
Guyana	-	-	-	-	-	-	2	2	-	-
Paraguay*	5	-	-	-	-	-	1	1	-	2

Annex 7 Indicators of the resource base for mycological investigations within tropical countries (adapted from Hawksworth, 1993a)

Country	New fungi described 1981/90 ¹	Human resources				Information resources				
		National Societies ²	BMS ³	MSA ⁴	IAL ⁵	BLS ⁶	Plant Diseases ⁷	Lichens ⁸	Macro-mycetes ⁹	Micro-mycetes ¹⁰
Peru	52	-	-	-	-	-	2	2	-	2
Suriname	1	-	-	-	-	-	1	-	1	-
Venezuela	135	-	4	1	1	1	2	2	3	3

Notes: The names of countries mainly follow Daume (1991); * = countries the boundaries of which are not all located between the Tropics of Cancer and Capricorn (i.e. between latitudes 24°N and 24°S); the information resources are scored on a subjective 1-5 point scale (1 = scattered mainly in short papers; 2 = checklists or other extensive compilations; 3 = monographs with descriptions and keys available for some groups; 4 = monographs available for most groups; 5 = exhaustive monographs available for all groups). Numbers in square brackets are based on information additional to that in the sources cited.

Sources: ¹*Index of Fungi* (1981-90), compiled from information extracted from the database by P.M. Kirk - some continental totals exceed those from the summation of the country figures due to the inclusion of species only localized to a region; ²Hall & Hawksworth (1990); ³British Mycological Society (G.W. Beakes, pers. comm., February 1992), total membership 2000 (11 % tropical); ⁴Mycological Society of America (Blackwell, 1988), total membership 1620 (9 % tropical); ⁵International Association for Lichenology (H.J. Sipman, pers. comm., February 1992), total membership 387 (12 % tropical); ⁶British Lichen Society (Gray (1991), total membership 535 (4 % tropical); ⁷Johnston & Booth (1983), M. Holderness (pers. comm., March 1992); ⁸Hawksworth & Ahti (1990); ⁹D.L. Hawksworth and D.N. Pegler (pers. comm., March 1992); ¹⁰D.L. Hawksworth and B.C. Sutton (pers. comm., March 1992).

Annex 8 Numbers and geographical origin of trainees at CABI Institutes 1985-92

AFRICA, S	P	E	M	B	T
Angola				2	2
Benin			1	5	6
Botswana	1	1			2
Burkina Faso	1	1		1	3
Burundi		1		4	5
Cameroon	2			2	4
Cape Verde			1	2	3
Central Af. Rep				2	2
Eritrea			1		1
Ethiopia	3	3	2	2	10
Gabon		1			1
Gambia			1		1
Ghana	1		2	6	9
Guinea				2	2
Guinea Bissau				1	1
Ivory Coast				3	3
Kenya		16	47	3	66
Liberia				1	1
Madagascar				2	2
Malawi	4	3	4	11	22
Mali		5			5
Mauritius	2	2	3	1	8
Mozambique		2	1		3
Namibia		1			1
Nigeria	4	4	21	3	31
Niger		2	1		3
Rwanda		1		3	4
Senegal	1				1
Sierra Leone	1		2		3
Somalia		2	3		5
South Africa			1		1
Sudan		1	3	3	7
Swaziland			1		1
Tanzania	6	7	10	4	25
Togo				3	3
Uganda	6	7	15	6	29
Zaire				2	2
Zambia		4	7	4	13
Zimbabwe	7	2	7	1	17
AFRICA, N					
Algeria			3		3
Egypt	1		17		18
Libya	2		1		3
Morocco	1				1
EUROPE					
Austria			1		1
Belgium	1		2		3
Crete				1	1
Cyprus	1	1	10		12
Denmark			3		3
Finland			4		4
France	1		1		2
Germany	2	1	6	6	15
Hungary			1		1

Annex 8 Numbers and geographical origin of trainees at CABI Institutes 1985-92

Iceland	1				1
Ireland			5		5
Italy	2		8		10
Malta			1		1
Netherlands		1		2	3
Norway	1		17		18
Poland			2	1	3
Portugal	1	2	7		10
Slovenia			1		1
Spain	1	1	11		13
Sweden	1		6		7
Switzerland			2	8	10
Turkey				1	1
United Kingdom	11	2	148		161
Yugoslavia			3		3
ASIA, E					
China			46 (21)	10	56
Brunei	1	1		1	3
Indonesia		8	7		15
Myanmar			1	1	2
South Korea			3	1	4
Malaysia	1	37	38	9	85
Philippines	2	2	3	48	55
Singapore	1	1	2	1	5
Taiwan			1		1
Thailand		4	1	9	14
Vietnam	1			3	4
ASIA, W					
Bangladesh		3	5	2	10
Bhutan				1	1
India	8	5	78)	8	99
Nepal			1		1
Pakistan	7	1	8	5	21
Seychelles		1	2		3
Sri Lanka	5	6	6	5	21
MIDDLE EAST					
Iran	3		2	1	6
Jordan	1				1
Qatar			1		1
Syria			2		2
Utd Arab Emirates			1		1
Yemen				2	2
AUSTRALASIA					
Australia	1		3		4
New Zealand			2		2
Fiji	1				1
Kiribati		1			1
Solomon Islands		1			1
Papua New Guinea	1	4		1	6
Tonga		2			2
Tuvalu				1	1
Western Samoa		2			2

Annex 8 Numbers and geographical origin of trainees at CABI Institutes 1985-92

CARIBBEAN

Antigua				1	1
Barbados		2	2	3	7
Belize				2	2
Dominica				2	2
Grenada			2	1	3
Guyana				2	2
Haiti				1	1
Jamaica		1		5	6
Trinidad	3	2	23	9	37
West Indies	5			5	10

AMERICAS

USA	2	1	1		4
Canada			4		4
Argentina			3		3
Brazil	1	1	58		60
Bolivia				3	3
Chile			9		9
Colombia		1	1	23	25
Costa Rica			2	2	4
Ecuador			2	2	4
Guatemala	1				1
Mexico	2		1		4
Nicaragua		1		31	32
Peru		1		2	3
Venezuela				4	4

TOTAL	111	163	715	304	1293
-------	-----	-----	-----	-----	------

Notes:

P	=	IIP
E	=	IIE
M	=	IMI
B	=	IIBC

1. Numbers include most visiting workers staying for 2 or more weeks.
2. Numbers are an underestimate as overseas course numbers are not always accurate.
3. No allowance is made for CABI staff teaching on non CABI courses

Annex 9

BIONET - The Concept for an International Network to Support Regional and National Biosystematic Services

T. JONES

Director, International Institute of Entomology, UK.

INTRODUCTION

A detailed description of the BIONET concept, its objectives, *modus operandi* and the means of implementing it has been provided in an earlier unpublished report by the same author, *A Global Network for Biosystematics of Arthropods and Microorganisms*. This paper seeks to summarize the conceptual, structural and operational features of BIONET and expand some of its major aspects in the context of the Caribbean subregion.

In brief, BIONET is a plan for a permanent mechanism for mobilizing, pooling and strengthening the world's wealth of biosystematic resources (both material and manpower) and a mechanism for facilitating the effective deployment of these resources in support of sustainable agricultural development in the best interests of man and his environment.

Among BIONET's particular concerns is that of ensuring that the best possible biosystematic services are readily and effectively available where they are most needed, i.e. in the presently resource-poor, agriculturally dependent countries of the Third World with their fragile but biodiversity-wealthy environments. The long-term objective of BIONET is to achieve a more equitable and appropriate distribution of biosystematic capabilities between developed and developing countries through the strengthening of Third World biosystematic resources.

THE CONCEPT

Collaboration between biosystematic institutions, centres of excellence, and individual specialists is central to BIONET and this in itself is not new. Such collaboration has been and continues to be a feature of the international biosystematic community, working together on specific common problems for mutual benefit. The record also shows that several types of collaborative mechanisms have been devised in earlier times designed to achieve formal and/or informal cooperation between institutions at the national and regional level. All too few of these were effectively implemented and most if not all that came into being appear to have enjoyed but a limited effective life-span. What the record clearly shows is that the need for some collaborative mechanism has long been recognized in biosystematic circles and the BIONET concept has emerged in response to that need.

It has naturally evolved against a background of past endeavours to create collaborative mechanisms and has taken earlier experiences into account. But BIONET is not rooted in any of the earlier mechanisms. It is not a lineal descendant of multifarious earlier ideas and notions nor an illegitimate brain-child of multiple parents. BIONET is a new approach to collaboration in the field of biosystematics based on the tried and tested strategy, conceived, promoted and sponsored by the United Nations under its programme of Technical Cooperation between Developing Countries (TCDC) - a strategy known as the Technical Cooperation Network (TCN).

BIONET in its full global dimension is conceived as a Technical Cooperation Network and likewise each individual sub-regional Locally Organized Operational Partnership (LOOP) is seen as a TCN in its own right. Furthermore, the proposed Consortium of Technical Support Institutions (BIOCON) designated to provide technical back-up and support for LOOPS and BIONET at large, is yet another TCN.

TECHNICAL COOPERATION NETWORKS

Purpose and Objectives

The prime function of a TCN is to mobilize the enormous potential of skills, knowledge and experience and the infrastructures to be found within the numerous institutions of Third World Countries, and the actual resources existing in developed country institutions, to establish and sustain the strongest and most economical technical partnerships dedicated to solving common problems.

Permanency, i.e. longevity, is inherent in the TCN concept, and self-help, mutual support and commitment to principles and responsibilities are the foundations on which TCNs are established.

Nature

A TCN is a permanent institutional mechanism for technical cooperation between countries, designed to achieve benefits and results.

It is a formal association and partnership between its member institutions designed to promote, enable and sustain the pooling of resources of its members to resolve a common problem for the benefit of all concerned.

It is problem and/or subject specific, sustainable and totally practically oriented.

It may be sub-national, national, subregional, regional or global in dimension.

Membership and Structure

Membership is generally restricted to institutions and professional bodies which in one way or another are active in the particular field of concern of the TCN and who have something practical to contribute.

Member institutions may include government, non-government, inter-government and parastatal bodies, independent research and development institutions, appropriate banks and private sector organizations.

In supranational TCNs there may be more than one member institution within any country.

Large TCNs may be organized into, and consist of, a number of sub-networks (or LOOPs) operating on a subregional level, but closely linked through a central technical support and coordinating facility known as the Technical Secretariat (TECSEC).

The Technical Secretariat is in itself a source of technical support but may also be a channel for and part of a richer and more comprehensive resource in the form of a technical support consortium.

Operation

Network member institutions themselves play the primary role in the initiation, organization and management of the TCN.

They have a firm commitment to the TCN, and accord it high priority in their programmes of work.

Member institutions share a common problem and have a clear perception of the mutual and shared benefits of cooperation.

There is strict observance of national identity, sovereignty, equality and mutuality of interests irrespective of the size, level of development, social and economic systems and situations of member-institution countries.

Member institutions contribute in cash and/or kind, full or partial support of programme inputs, e.g. experts, consultants, research and training facilities, equipment, materials and supplies etc.

A TCN has one elected institution which is designated as the Network Coordinating Institution (NECI) - or as proposed for BIONET designated as the NODE (Network Organization, Development and Execution Institute) which is assigned the task of organizing the implementation of the TCN's programmes, serving as the communications centre and being responsible for the receipt and dissemination of information and generally functioning as the focal point of the TCN and its link with the Technical Secretariat.

Where there are several member institutions in one country, one of these is elected as the National Coordinating Institution (NACI) to serve with the NECI or NODE on the TCN coordinating body.

In addition, any member institution may be elected Network Coordinating Institute for specific leadership activities (eg. specific taxa work programmes, curation training etc.) or to lead Task Forces.

Where the TCN consists of a number of sub-TCNs or LOOPS, the NECIs or NODEs together with the Technical Secretariat may serve as a Network Coordinating Committee.

BIONET AS A TCN

It is envisaged that BIONET would adhere closely to the TCN requirements mentioned above, but the TCN strategy has considerable flexibility to allow for local requirements and situations. Some of BIONET's salient features as a TCN include the following :-

(1) BIONET is global in dimension, allowing access for members to each and every known biosystematic resource.

(2) It is composed of closely inter-linked, self-standing, democratically organized subregional LOOPS, with all member institutions having equal footing, and the resources of members being pooled for the benefit of all.

(3) The *modus operandi* of LOOPS (i.e. the pooling of resources to optimize their use and the appropriate delegation of work programme responsibilities among member institutions) allows for the most cost-effective use of existing institutional budgets and facilitates the pursuit of biosystematic endeavours using purely local resources.

(4) LOOPS satisfy the major qualifying criteria for international donor assistance by their permanency and long-term locally executed work programmes embracing research, agricultural, environmental and biodiversity services, training and institutional strengthening.

(5) Individual institutions and LOOPS, through their elected NODE, have access to managerial and technical support from the Technical Secretariat (TECSEC) and the expertise and resources of the BIONET Consortium of technical support institutions (BIOCON).

IMPLEMENTATION OF BIONET

Procedures

Experience with TCNs elsewhere has shown that the process of establishing a network such as BIONET is best accomplished through a sequence of steps which give the TCN legitimacy in the eyes of UNDP in particular and also other sponsors, and which lay the foundations for future effective networking. It is especially important that these steps be followed if the aspiring subregion is to attract the "catalytic financial assistance" available under the UNDP financing project entitled "Promotion of Action-oriented TCDC Activities". In brief these steps involve :-

(1) The identification of a common subregional problem which, it is considered, might most effectively (technically and economically) be addressed through sustained technical cooperation between the institutions concerned (e.g. the inadequacy of biosystematic services).

(2) The identification at national level of the priority problem areas and the needs of the field in which the TCN is to be organized.

(3) The identification at national level of what technical cooperation is needed from others and, conversely, what technical cooperation can be offered to other TCN members.

(4) The identification of all subregional and other (external) technical support institutions whose participation in the TCN is deemed necessary and/or desirable.

(5) The convening of a Workshop involving all those institutions identified under (4) above; to review and report upon terms (1-3) above; to discuss and decide upon the desirability of creating a TCN and if it is so decided, to formulate an official proposal for a TCN for submission to all governments concerned giving the proposed work programmes and the identity of member institutions, technical support institutions and the NODE, NACI and other coordinating institutions.

(6) On receipt of governments' endorsement initiate the TCN.

The catalytic financial assistance referred to above is specifically ear-marked by UNDP to sponsor the Workshop described under (5) above, and is intended to cover the cost of attendance of delegates.

Prospects

At this precise moment BIONET is but a notion, an idea and a blueprint for action. It is a proposal and a plan, which has been well received by those concerned, but still awaits adoption and implementation. BIONET will come into being when its first subregional LOOP and its attendant Technical Secretariat and BIOCON are born. Where might this birth take place?

It is encouraging to report that a number of larger countries and some subregions with particular environmental concerns and especially those with pesticide pollution problems, which are anxious to embark on substantial biological control programmes, have expressed genuine interest in establishing a BIONET LOOP.

But as many of the eminent local scientists indicated in their addresses to this Workshop, and indeed as this Workshop itself testifies, nowhere is there greater concern, enthusiasm and positive action in the field of biosystematic collaboration than in the Caribbean subregion. The vision and foresight and the continuity of purpose of the sub-regional institutions and organizations is impressive and they deserve success in their endeavours to establish adequate and appropriate subregional biosystematic capabilities.

The Caribbean subregion has stolen a march on all others in this field of biosystematic collaboration and has gained a significant comparative advantage which could allow the subregion to pioneer the TCN strategy in the biosystematic context. The Caribbean subregion could be the founding father or midwife of BIONET and it is hoped that this Workshop will take prompt and effective practical action to make this a reality.

But how is BIONET to be put in place, how are LOOPS to be established together with their external technical support services?

There are clearly two issues - - implementation discussed above and funding which are inter-related.

What are the prospects of donor assistance?

Following the lead of UNDP, donor agencies are generally unattracted to short-term isolated projects and have strong preferences for long-term programmes with built-in sustainability. Nothing could be longer-term or more evidently self-sustaining than the subregional technical cooperation networks which constitute BIONET LOOPS.

Similarly, following UNDP's lead, donors favour programmes where local, national and subregional execution of programmes is evident. In BIONET LOOPS it is the member institutions themselves which play the primary role in the initiation, organization and management of the LOOP.

Another important point is that all donors, without exception, favour programmes in which sustainable agricultural development is the prime objective, i.e. programmes which are designed to increase agricultural production whilst protecting the environment and conserving biodiversity. Biosystematic services, as this Workshop and many other international fora have proclaimed, are essential for, and fundamental to, agricultural production, environmental protection, and biodiversity conservation.

BIONET would seem to have the right pedigree to suggest that it will find favour amongst donors and, although it is not possible nor prudent to announce here and now that donor support is guaranteed, it is fair to say that there are very good grounds for believing that some donors are not only willing, but are actually keen to support BIONET (e.g. in the provision of technical support services) and we know that catalytic finances could be available to support LOOP-establishment exercises.

It would seem that donor assistance opportunities for subregional LOOPS are better than they have ever been and they should be taken up without undue delay.

[This paper was first published in: *Biodiversity in the Caribbean. Report and abstracts of an international workshop on diagnostic services for agriculture and the environment* (A.M. Ainsworth & D.L. Hawksworth, eds): 15-20, 1992. ISBN 0 85199 832 6. CAB International: Wallingford, UK.]

